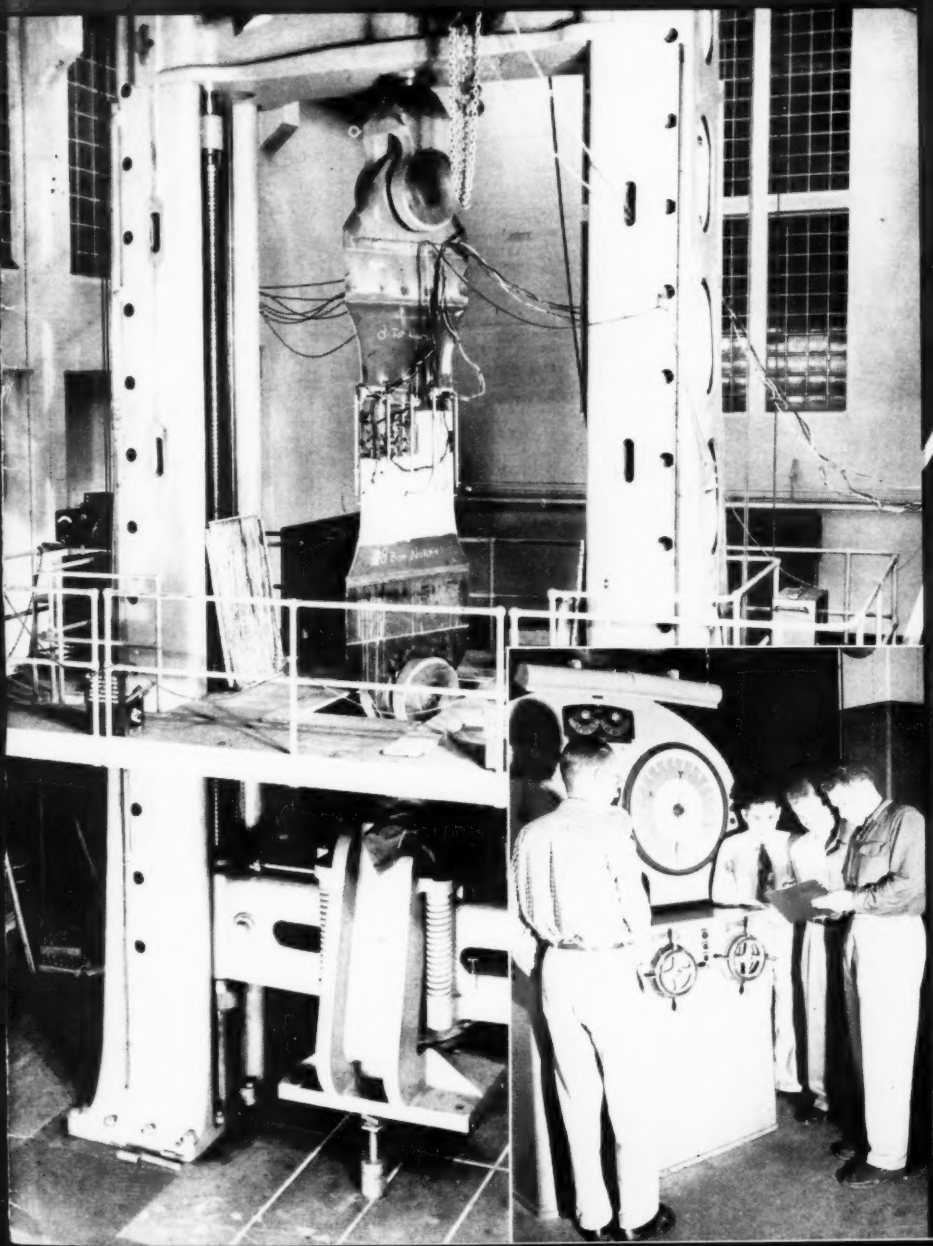
The TREND IN ENGINEERING

at the University of Washington



In this issue:

- Water Injection in a Small Jet Engine
- University Active in Air-Pollution Study
- Control of Driving Source Impedance and its Effect on Loudspeaker Response
- Separation of Substances by Dialysis Through Cellophane Membranes
- Glacial Geology of Seattle
- Sheathing Paper as a Causal Agent in Paint Failures

October, 1950

VOL. 2, No. 4

THE RAPIDLY DIMINISHING TIME INTERVAL between discoveries in science and their application to technology . . . is particularly marked in the technology of war, where the desperate need of survival has speeded up normal processes of application and development. During World War II, a very large percentage of our scientific people went to work on weapons. It is sometimes thought that the vast expenditures made on experimental work during the war were expenditures on science. This is not correct. Actually scientific research came almost to a complete halt in this country between 1940 and 1946. What the scientists were doing in this period was to apply the knowledge and techniques they already had to practical problems of warfare. This scientific knowledge had been built up over a long period of years. Even from the most narrow point of view of national security, it was clear after the war that basic research must be resumed and that men must be trained to do such work. . . . At the same time we are confronted with the need of secret research for the further development of weapons of war. Such research requires large numbers of scientists who would normally be doing open research. We have, therefore, to learn to live in a scientific world that is today only partly free. This leads us to a reassessment of the importance of freedom in science and its relation to freedom in the society as a whole. . . .

"We are in a dilemma that is not confined to science and technology but is more acute there than elsewhere. It can be simply stated by the questions: How much should we talk? or, How much talk should be permitted? Everyone is agreed that the technological details of atomic bombs and other weapons should be kept secret; everyone is agreed that the public should be informed on technical matters that affect public policy; everyone is agreed that we must continue to teach students the principles of science without restriction, and that scientific research and publication are fine things that should be fostered generally. Everyone agrees that freedom of speech is something we would fight to defend—and everyone agrees that the sixty thousand employees of the Atomic Energy Commission and its contractors should not have complete freedom of speech. . . .

"The best thing we can do is to balance the advantages of revealing information to our own people against the dangers of giving that information to a potential enemy. In doing this, we must remember that our future strength in military technology cannot depend entirely on work in secret government laboratories. It will certainly depend also on the vitality of our educational program, on the research of innumerable university and industrial laboratories, and on the progressiveness of our industrial technology. A policy of exaggerated secrecy would destroy the strength it was intended to protect."

—From "The Place of Science in a Free Society," by Henry D. Smyth, United States Atomic Energy Commission, in *American Scientist*, July, 1950.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. The results of the investigations are published in the form of bulletins, technical notes, and reports. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

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Vol. 2 No. 4

Published quarterly, in January, April, July, and October, by the Engineering Experiment Station at the University of Washington to reflect the current highlights of its accomplishments and to report progress in its program of investigation and research.

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127 More Hall
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Seattle 5, Washington

Entered as second-class matter March 7, 1949, at the post office at Seattle, Washington, under the act of August 24, 1912.

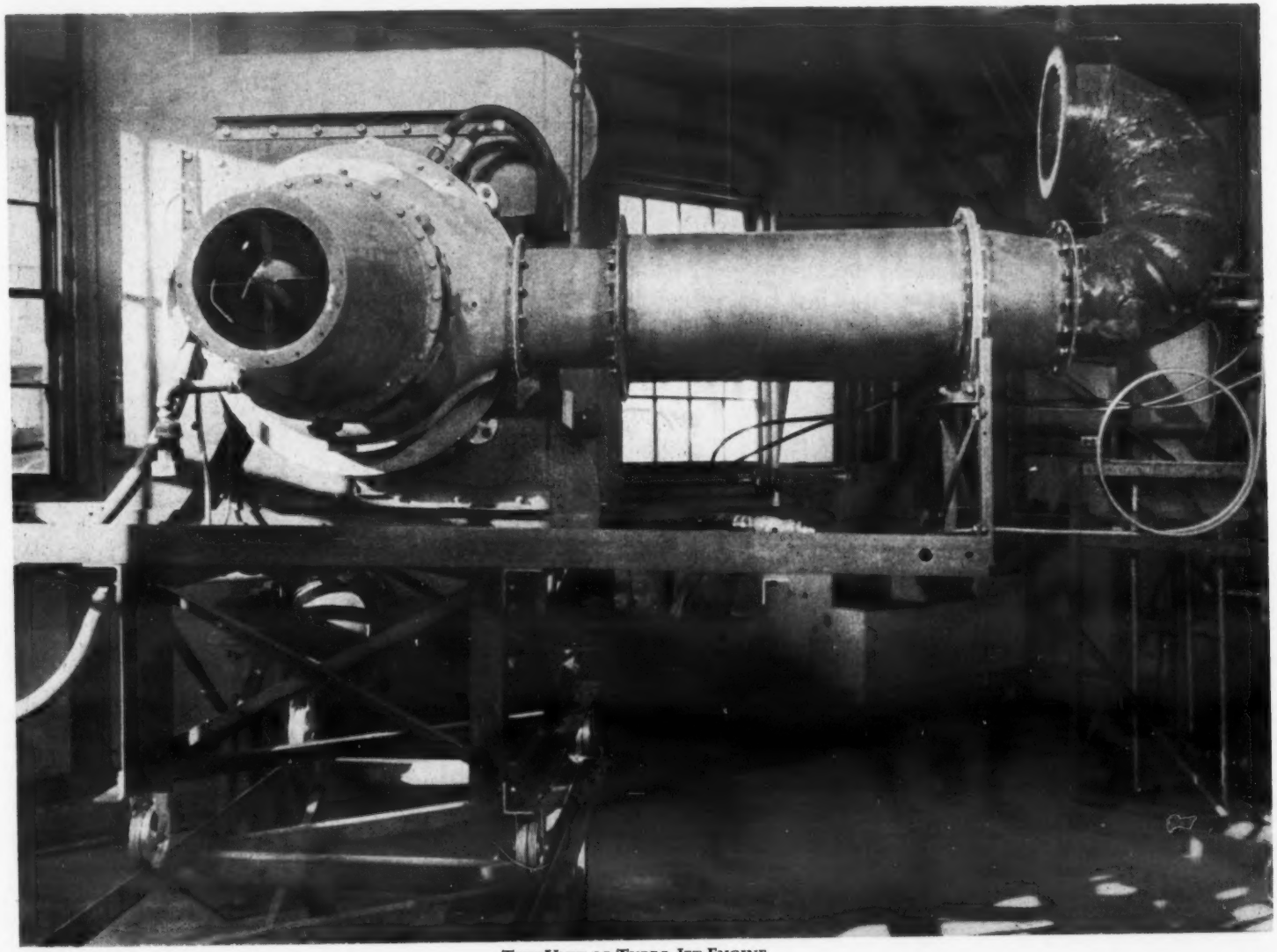
CONTENTS

Water Injection in a Small Jet Engine *Oliver A. Foss* . 5
University Active in Air-Pollution Investigation . . . 8
1949-50 Increased Enrollment of Graduate Engineers . . 8
Control of Driving Source Impedance and Its Effect on Loudspeaker Response *R. L. Tanner* 9
British Engineer Studies New Bridge 13
Separation of Substances by Dialysis Through Cellophane Membranes *R. E. Davis, Q. P. Peniston, J. L. McCarthy* 14
Post-Convention Seminar Held for Humanistic-Social Division 18
Glacial Geology of Seattle *J. H. Mackin, D. R. Mullineaux, W. J. Stark* 19
Pacific Northwest Industrial Research Conference . . . 21
How Metals Fracture (Abstract from *Product Engineer* of article by C. F. Tipper in *Metallurgica*) 22
City Planning Expert to Lecture 23
Sheathing Paper as a Causal Agent in Paint Failures *B. L. Grondal* 24
Engineering Research Dividends 27
Notes and Comments 28

COVER

Tension test of a large plate in the 2,400,000-lb capacity universal testing machine in the Structural Research Laboratory of the Department of Civil Engineering. This test is one of a broad program of similar tests sponsored by the Bureau of Ships, Department of the Navy. The purpose of this research project is the investigation of the efficiency of different types of arc-welded reinforcement around openings in structural steel members.

Inset (left to right): Dr. D. Vasarhelyi, Henry Cheng, Keith Kenworthy, Dr. R. A. Hechtman. Dr. Hechtman is in charge of the Navy tests, assisted by Dr. Vasarhelyi.



TEST UNIT OF TURBO-JET ENGINE

WATER INJECTION IN A SMALL JET ENGINE*

OLIVER A. FOSS
Research Fellow in the Engineering Experiment Station

O. A. Foss

In a turbo-jet engine, incoming air is compressed and directed to combustion chambers where fuel is added and burned. The resulting working mass passes through the turbine driving the compressor and is then directed through the jet cone which produces a high-velocity jet.

The thrust developed in a turbo-jet is derived from the reaction of the acceleration of the working mass and is expressed by the equation for static thrust:

$$T=\frac{W}{g}V_j$$

where T = thrust in pounds, W = working mass rate in pounds per second, V_j = velocity of the exhaust jet in feet per second, and g = 32.2 feet per second per second. Thus an increase in either the working mass rate, or velocity of the jet, or both, would increase the thrust of a unit.

For a given working mass leaving the jet cone, the velocity of the jet is dependent only upon the area of the cone. Three basic changes occur as the jet cone area is decreased. First, the increased restriction causes a decrease in the air rate through the compressor and also a slight increase in the compressor outlet pressure. Second, as the required pressure drop across the jet cone is increased, the remaining pressure drop across the turbine is decreased. The increase in compressor outlet pressure is not nearly sufficient to compensate for this decrease of available turbine pressure drop. Third, to make up for this reduced turbine pressure drop and decreased air flow, the temperature entering the turbine nozzle-box would have to be increased to cause a greater working volume. This cannot be done because the temperature of the working mass entering the nozzle box is designed as the highest temperature at which the buckets can successfully operate.

It therefore appears that some other path must be taken to increase the thrust of a given turbine. The program followed in Engineering Experiment Station Project No. 70 examined water injection as a means for increasing thrust.

There are two logical points in the turbo-jet cycle at which water could be introduced to the working fluid, either at the compressor inlet (precompression injection) or between the combustion chambers and the nozzle-box (post-compression injection), as shown in Fig. 1.

Precompression injection has several effects. The amount of water evaporating between the injector nozzles and the compressor impeller depends upon such physical factors as the degree of atomization, the temperature and relative humidity of the inducted air, the amount and temperature of the injected water, turbulence in the induction duct, and the length of the induction duct. This evaporation of water tends to decrease the temperature of the air at the beginning of compression, thereby increasing the specific gravity of the entering air.

Within the compressor, the presence of the unevaporated water droplets has the effect of an infinite number of inefficient compressor intercoolers. Thus the air is cooled throughout the compression process, allowing isothermal compression to be approached, and decreasing the amount of compressor work required per pound of air. The increased density of the air throughout the compression process results in an increased air rate and also an increased compressor outlet pressure. Any water which remains unevaporated upon leaving the compressor is swept with the air stream to the combustion chamber where it is converted to steam, thus increasing the working volume. However, all the heat required to evaporate the water anywhere in the cycle must be furnished by the fuel.

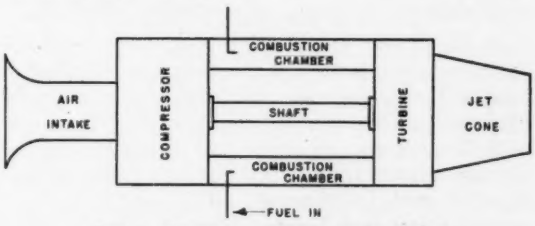


FIG. 1. SCHEMATIC DIAGRAM SHOWING TURBO-JET COMPONENT ARRANGEMENT

*Condensed from the author's thesis submitted in partial fulfillment of the degree of M.S. in Mechanical Engineering. The investigation was carried on under the supervision of M. Guidon, Instructor in Mechanical Engineering. The author was assisted by Kenneth Hwang-fu, Research Fellow in the Engineering Experiment Station.

Post-combustion injection has but one effect, that of increasing the working mass and volume. The steam formed increases the working volume, permitting use of a smaller sized cone, with the result that thrust is increased without raising the nozzle-box temperature. Post-combustion injection appears to have no advantage since any water injected before the compressor would have the advantages of precompression injection and would ultimately be delivered to the post-combustion zone. However, when precompression injection is used, the amount of water that can be injected would probably be limited by one of the following factors:

1. The possibility of erosion of rotating compressor components
2. The possibility of combustion interference and lowered flame stability
3. The possibility of the accumulation of unevaporated water which would drain to the combustion chamber, turbine, or compressor, depending upon the turbo-jet component arrangement

Apparently there would be a maximum amount of water injection beyond which unevaporated water would have a detrimental effect upon the turbine. This amount would depend upon many factors, such as the degree of atomization, distance between the injectors and the nozzle-box, temperatures and velocities involved, and the degree of completion of the combustion process at the point of injection, and therefore could be determined only experimentally.

No attempt has been made to offer a general or a qualified thermodynamic analysis of the relative effects of the factors involved in either type of injection because there are too many indeterminate factors each of which would require experimental examination. Further, no attempt was made to predict absolute results on a theoretical basis for the turbo-jet unit used in obtaining the experimental results presented in this paper because the undetermined and indeterminable items would require too many assumptions and over-all correction factors.

Thus the experimental data used here show only the over-all effect of each of the two types of water injection and no attempt has been made to evaluate each effect or correlate over-all findings to theory.

In the present investigation two series of experiments were conducted, one to show the net effect of precompression injection, and a second to show the net effect of post-combustion injection. To accomplish this purpose, the small, laboratory size, turbo-jet shown in the front illustration was designed, constructed, and instrumented. This unit was built around a standard General Electric aircraft turbo-supercharger.

The tests were run at a constant speed of 20,500 rpm with constant jet cone areas. The water rate was varied from 0 to 40 gallons per hour for the precompression injection, and from 0 to 225 gallons per hour for the post-combustion injection. Three different jet cone sizes were run under these conditions, but only the data observed for the medium sized cone were used in this paper. The curve shapes derived from data of the other two cone sizes are similar.

Water drains were placed at three places: the compressor outlet, the bottom of the combustion chamber, and the bottom of the nozzle-box. The water was forced by gravity into reservoirs, and indicators were located at the control board to warn of high accumulation rates. The reservoirs could be emptied from the control board.

Precompression Injection Test

As soon as the maximum water rate was reached, combustion became unstable and blow-out occurred, making test runs impossible. Below the maximum rate, no water accumulated in the water traps, but above this rate water was found to have drained from both the combustion chamber and the compressor outlet traps, indicating that the two readily determined factors limiting the amount of precompression injection reached their optimum points in the same range of water rates. However, the amount of water accumulation was very small and combustion instability must be considered the limiting factor.

After the tests had been completed, it was found that a coarse, poorly atomized spray did not have as adverse an effect upon the combustion as did the finely divided spray. This would allow a greater water rate to be used before the maximum rate would be limited by combustion instability. A comparison of the relative amounts of water accumulation was not made. The effectiveness in the compressor of the coarse spray did not appear to be changed from that of the same amount of fine spray injection. The test results, as implied, were made using a finely atomized spray.

Figure 2 shows a portion of the results obtained from the test. Thrust was increased 7.5 per cent with a decrease in nozzle-box temperature of about 50 degrees for a water rate of 40 gallons per hour. Specific fuel consumption increased a maximum of 4 per cent. Additional observations showed that the compressor air rate increased slightly, the compressor outlet pressure increased about 6 per cent, and the compressor outlet temperature dropped from 262 degrees to 149 degrees. None of these results deviated far from those predicted from a pressure-volume diagram analysis of water injection.

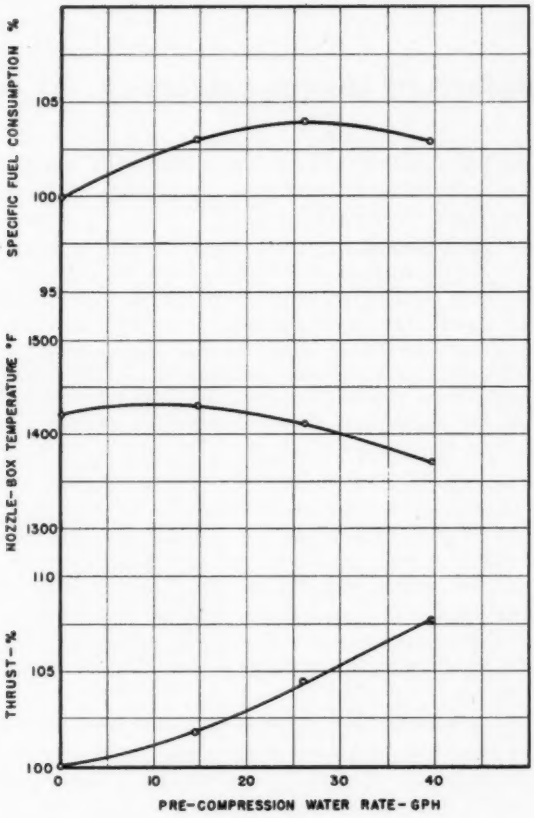


FIG. 2

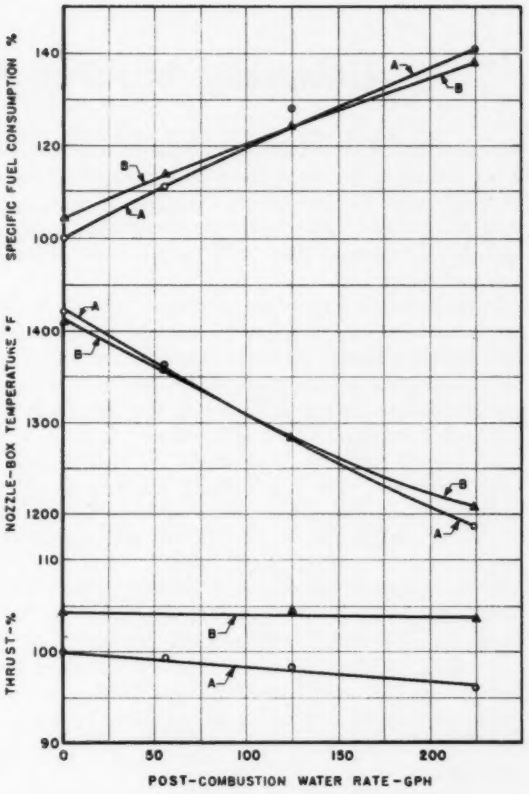


FIG. 3

Post-Combustion Injection Test

The tests for post-combustion injection (Fig. 3) were run under two sets of conditions. The first (curve A) merely varied the amount of water to post-combustion injectors; in the second (curve B), in addition to the post-combustion injection, a 26-gallon-per-hour precompression injection was maintained. The two sets of curves are plotted on the same graph for comparison purposes.

The factor limiting the maximum water rate was not, as expected, the inability to evaporate the water, but was a materials problem. The combustion chamber was designed as a 22-inch, straight-through, can-type burner. Between the combustion chamber outlet and the nozzle-box inlet, an 18-inch duct was inserted, with injection occurring 5 inches from the combustion chamber end. This duct had no cooling provisions and the working volume leaving the combustion chamber had to contain sufficient heat to vaporize the injected water. Therefore, in the 5-inch section of duct between the combustion chamber and the injectors, the average temperatures were higher than at any other place in the cycle. Although this section was constructed of stainless steel, its permanent deformation due to high temperature creep was easily visible. The limit determined by lack of total evaporation of water was never reached and all the water appeared to be fully evaporated before leaving the nozzle-box.

Figure 3 shows that thrust changed only slightly as the water rate increased. Nozzle-box temperature decreased as much as 240 degrees, while the specific fuel consumption increased up to 40 per cent.

Conclusions

The experimental data obtained from this work indicate that precompression injection could increase thrust by as much as 25 per cent in some of the larger jet units. This opinion is based on the belief that the extremely high heat releases in the combustion chambers of these power plants would allow injection of perhaps three times the number of pounds of water per pound of air before reaching the limit.

(Continued on page 28)

University Active in Air-Pollution Investigation

INCREASING PUBLIC CONCERN with the problem of air pollution, stemming from municipal recognition of conditions in Pittsburgh, St. Louis, and Los Angeles County, was high-lighted by the Donora episode of October, 1948, in which twenty persons lost their lives.

Aware that this problem challenges the combined resources of several fields of knowledge, a committee representing four University departments met last May to initiate an investigation of air pollution in the Northwest, and, specifically, in the Seattle area.

The Air Pollution Committee includes R. G. Tyler, Professor of Sanitary Engineering, F. B. Farquharson, Director of the Engineering Experiment Station, Dr. L. E. Powers, Director of the Department of Public Health, Dr. P. E. Church, who heads the Department of Meteorology, Dr. J. Leon Sealey, consultant, and A. W. Green, sanitary engineer, both of the Department of Public Health, and W. W. Philbrick, Assistant Director of the Station.

Professor Tyler has carried on air-pollution investigations for several years, and his 1948 report on smoke abatement in Tacoma has resulted in the appointment by that city of an expert to carry on its program.

Since obviously an understanding of atmospheric phenomena plays an important part in any consideration of air pollution, the University is fortunate in having its own well-developed department of meteorology which grew out of Dr. Church's early association with the air-pollution problems at the Hanford project, with which he is still connected as consultant. He has also been consulted regarding air-pollution problems at Los Alamos, Brookhaven, and Oak Ridge.

Plans were made to pool the resources of all the departments represented, with the object of establishing pilot studies in Seattle and elsewhere to aid and guide Washington communities in meeting the problem of air contamination.

When the field and laboratory functions of the Division of Industrial Hygiene of the State Department of Health were recently discontinued, the Public Health Department of the University came into possession of the equipment of the State Laboratory. This equipment, the most complete in the Northwest, enables the University to provide expert advice and service in all phases of the air-pollution problem.

One of the important activities growing out of the meetings of the committee was the first Seminar on Air Pollution, which was held on the University of Washington campus August 21-23. Attendance was limited to representatives from the University and City of Seattle departments of public health and engineering, and from the University Department of Meteorology. Considerable emphasis was laid on instrumentation in the field and laboratory, with special reference to methods of sampling dust, smoke, etc.

A certain amount of field work, under the direction of Mr. Green, is already in progress, confined largely to the trough of the Lake Washington Canal, which is the source of some of the most serious contamination in the Seattle area. A number of dust-collecting stations have been established, and continuous air samples are now being taken from the meteorological tower on the campus. In addition, the Department of Meteorology has been recording solar radiation for comparison with similar observations obtained at the Seattle-Tacoma airport.

While the committee's primary concern is with the effects of air pollution on public health, the importance of the nuisance factor and of the economic and esthetic phases is also recognized.

1949-50 INCREASED ENROLLMENT OF GRADUATE ENGINEERS

Average enrollment of graduate students in the College of Engineering for each of the three quarters, 1949-50, was 188 in comparison with 164 for 1948-49 and 142 for 1947-48. Departmental averages were as follows: aeronautical, 22; chemical, 46; civil, 35; electrical, 41; mechanical, 34; mineral, 12.

During the period June 1, 1949, to June 1, 1950, 66 graduate students held research fellowships in the Engineering Experiment Station. Of these, 58 were assigned to projects in the College of Engineering, two were graduate students in the Geology Department, and six in the College of Forestry.

CONTROL OF DRIVING SOURCE IMPEDANCE AND ITS EFFECT ON LOUDSPEAKER RESPONSE*

R. L. TANNER
Instructor in Electrical Engineering

R. L. Tanner

A factor of extreme importance in determining the response characteristic of loudspeakers, and one which is not usually given sufficient consideration in design, is the effective driving source impedance. The mechanical system of a loudspeaker has an electrical analogue which is the series resonant circuit shown in Fig. 1. This equivalent circuit is based on the similarity between the differential equations of motion for the loudspeaker and the Kirchoff circuit equations for the resonant circuit. In the analogy the mass of the moving system (cone, voice coil, and air mass) is represented by L, the compliance of the suspension by C, and the total dissipation (energy lost in flexing the suspension plus energy radiated as sound) by R. The current flowing in the electrical circuit is analogous to the velocity of motion of the loudspeaker, $\dot{x}$, where $\dot{x}=\frac{dx}{dt}$, and the voltage applied to the circuit corresponds to the force applied to the loudspeaker moving system by the interaction of the current in the voice coil with the magnetic field in the air gap. The motion of the voice coil in the magnetic field causes a counter emf to be generated in the voice coil, and it is possible to represent this counter emf as a voltage drop across a hypothetical impedance called the motional impedance. The relation between this motional impedance, $\mathbf{Z}_{mot}$, and the mechanical impedance of the loudspeaker, $\mathbf{Z}_{mech}$, shown in Fig. 1 is derived as follows.

The force produced on the loudspeaker voice coil carrying a current of I amperes is

$$\mathbf{F}=\frac{\mathbf{B}lI}{10}\text{ dynes,} \tag{1}$$

where $\mathbf{B}$ is the magnetic field strength of the air gap in gauss and l is the length of voice-coil wire immersed in the magnetic field. This force, when applied to the loudspeaker moving system with a mechanical impedance of $\mathbf{Z}_{mech}$ mechanical ohms, results in a motion of velocity $\dot{x}$ centimeters per second according to equation

$$\dot{x}=\frac{\mathbf{F}}{\mathbf{Z}_{mech}}=\frac{\mathbf{B}l}{10\,\mathbf{Z}_{mech}}. \tag{2}$$

The motion produces in turn a counter emf, or motional voltage, of magnitude

$$E_{mot}=\frac{\mathbf{B}l\dot{x}}{10^8}=\frac{\mathbf{B}^2l^2I}{10^9\,\mathbf{Z}_{mech}}, \tag{3}$$

$$\mathbf{Z}_{mot}=\frac{E_{mot}}{I}=\frac{\mathbf{B}^2l^2}{10^9\,\mathbf{Z}_{mech}}. \tag{4}$$

The motional impedance is seen to depend on the reciprocal of the mechanical impedance, or, since $\mathbf{Z}_{mech}$ is a series resonant circuit, to have the characteristics of a parallel resonant circuit.

The motional impedance is not the only impedance presented by the loudspeaker to the driving amplifier.

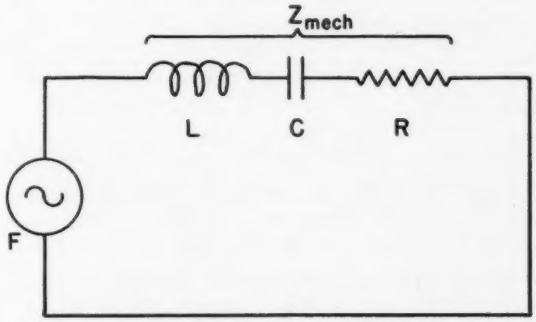


FIG. 1. ELECTRICAL ANALYSIS OF LOUDSPEAKER

*The investigation upon which this report is based was carried on as Engineering Experiment Station Project No. 68, under the supervision of the author. J. H. Whiting and W. F. Nielsen assisted as research fellows.

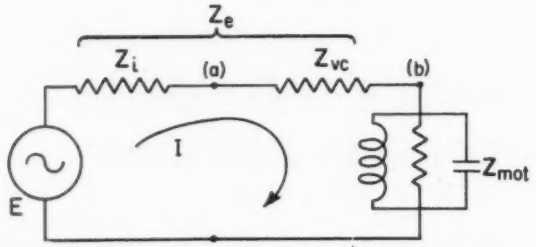


FIG. 2. EQUIVALENT CIRCUIT OF LOUDSPEAKER AND DRIVING AMPLIFIER—ELECTRICAL POINT OF VIEW

The total impedance includes the impedance of the voice coil—chiefly resistive—which, at all but the resonant frequency of the speaker, is considerably larger than the motional impedance. The total equivalent circuit of the speaker and the driving amplifier can thus be represented, from the electrical point of view, as in Fig. 2. The driving amplifier is represented by a Thevenin's equivalent voltage source in series with the effective internal impedance of the amplifier, $\mathbf{Z}_i$, and the loudspeaker by the series combination of the voice-coil impedance, $\mathbf{Z}_{vc}$, and the motional impedance, $\mathbf{Z}_{mot}$. From the equivalent circuit of Fig. 2 it is obvious that the amplifier internal impedance and the voice-coil impedance can be grouped into an equivalent driving source impedance, $\mathbf{Z}_e$, which is the series combination of the two. For the range of frequencies where it is of concern, this equivalent series impedance is very nearly a pure resistance.

The effect of the driving source impedance, $\mathbf{Z}_e$, can be analyzed from the point of view of the equivalent electrical circuit of Fig. 2, but it is more profitable to carry out the analysis by referring the entire system, including the amplifier and driving source impedance, to the equivalent mechanical circuit. This is done in the following set of equations.

The summation of voltages around the circuit of Fig. 3 gives the equation

$$E - I\mathbf{Z}_e - I\mathbf{Z}_{mot} = 0. \tag{5}$$

From the previous derivation,

$$\mathbf{Z}_{mot} = \frac{\mathbf{B}^2l^2}{10^9\,\mathbf{Z}_{mech}}, \tag{4}$$

and

$$\mathbf{F} = \frac{\mathbf{B}lI}{10} = \dot{x}\mathbf{Z}_{mech}, \tag{2}$$

so that the current, I, can be expressed as

$$I = \frac{10\,\dot{x}\,\mathbf{Z}_{mech}}{\mathbf{B}l} = \frac{10\mathbf{F}}{\mathbf{B}l}.$$

Substituting these expressions into Eq. (5) gives

$$E - \frac{10\,\mathbf{F}\,\mathbf{Z}_e}{\mathbf{B}l} - \frac{\dot{x}\,\mathbf{B}l}{10^8} = 0.$$

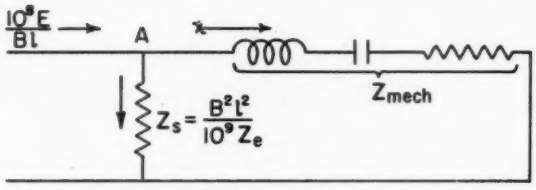


FIG. 3. EQUIVALENT CIRCUIT OF LOUDSPEAKER AND DRIVING AMPLIFIER—MECHANICAL POINT OF VIEW

On multiplying through by $\frac{10^8}{\mathbf{B}l}$ and transposing, the equation becomes

$$\frac{10^8 E}{\mathbf{B}l} = \frac{\mathbf{F}}{\frac{\mathbf{B}^2l^2}{10^9\mathbf{Z}_e}} + \dot{x}. \tag{6}$$

The terms of Eq. (6) are seen to have the dimensions of mechanical velocity which is the analogue of current in the electrical circuit. Whereas Eq. (5) represented the sum of voltages around a loop according to Kirchoff's voltage law, Eq. (6) can be construed as representing the sum of currents to a point according to Kirchoff's current law, and information contained in the equation can be put into the equivalent circuit of Fig. 3. The term on the left represents a mechanical current of magnitude $\frac{10^8 E}{\mathbf{B}l}$ flowing to the junction A. The second term on the right is the motional velocity or mechanical current of the speaker moving system, and is represented as flowing in a branch of impedance, $\mathbf{Z}_{mech}$. The first term on the right gives the effect of the driving source impedance. It represents the mechanical current which flows in an impedance $\mathbf{Z}_s = \frac{\mathbf{B}^2l^2}{10^9\mathbf{Z}_e}$ when a force $\mathbf{F}$, which is the mechanical force on the voice coil ($\mathbf{F} = \dot{x}\,\mathbf{Z}_{mech}$) is applied to it. Figure 3 is thus similar to Fig. 1. From the mechanical point of view, however, it is seen that the amplifier must be considered as a current source shunted by an impedance which depends inversely on the equivalent driving source impedance, $\mathbf{Z}_e$, and directly on the square of the $\mathbf{B}l$ product of the speaker. Thevenin's theorem permits the circuit of Fig. 3 to be further transformed to the circuit of Fig. 4, where the driving amplifier is represented as a voltage source of magnitude $\frac{\mathbf{B}lE}{10\mathbf{Z}_e} = \frac{10^8\,E\mathbf{Z}_s}{\mathbf{B}l}$ having the effective internal impedance $\mathbf{Z}_s$.

The reader can convince himself of the validity of the representation by considering the effect of variations in $\mathbf{Z}_e$. If, for example, $\mathbf{Z}_e$ is reduced to zero, Figs. 3 and 4 indicate that the motional

velocity, $\dot{x}$, of the voice coil will be independent of frequency, depending directly on the equivalent voltage, E, of the driving source. Referring to Fig. 2, it is seen that this is also the behavior to be expected on the basis of the equivalent electrical circuit. If $\mathbf{Z}_e$ is reduced to zero in Fig. 2, the constant voltage E is applied to the motional impedance; in other words the motional voltage must be constant. Since the motional voltage is proportional to the velocity of the voice coil in the magnetic field of the speaker, this is equivalent to saying that the velocity of the voice coil is constant and independent of frequency.

There are several reasons for considering the speaker system from the mechanical rather than the electrical point of view. These are, first, that speakers of comparable size all have approximately the same mechanical characteristics; second, that the magnetic gap strength and effective driving source impedance are conveniently accounted for because they affect only the element $\mathbf{Z}_s$; and third, that the effects of baffles are most simply considered from the mechanical point of view. For example, a simple enclosure merely increases the effective stiffness, and can be considered as a series capacitor in the mechanical circuit.

In making use of the equivalent circuit of Fig. 4 to calculate the response of a loudspeaker, another important factor must be considered. This is the fact that the radiation resistance of a loudspeaker in an enclosure or infinite baffle increases as the square of the frequency over the range of frequencies for which the speaker diameter is small compared to the wavelength. Most loudspeakers operate in this region for a range of several octaves in the vicinity of the resonant frequency. The low-frequency response of a loudspeaker in an infinite baffle, including the effects of this variation in the radiation resistance, has been calculated for several different values of the impedance $\mathbf{Z}_s$ and plotted in the curves of Fig. 5. Since the only effect of the enclosure is to raise the resonant frequency by increasing the effective stiffness of the speaker, the curves also apply to a speaker in a simple enclosure. The curves give relative response of a speaker as a function of the frequency relative to the resonant frequency. The magnitude of $\mathbf{Z}_e$ is given in terms of X_r the reactance at resonance of the reactive elements in Fig. 4, and can be applied to any speaker.

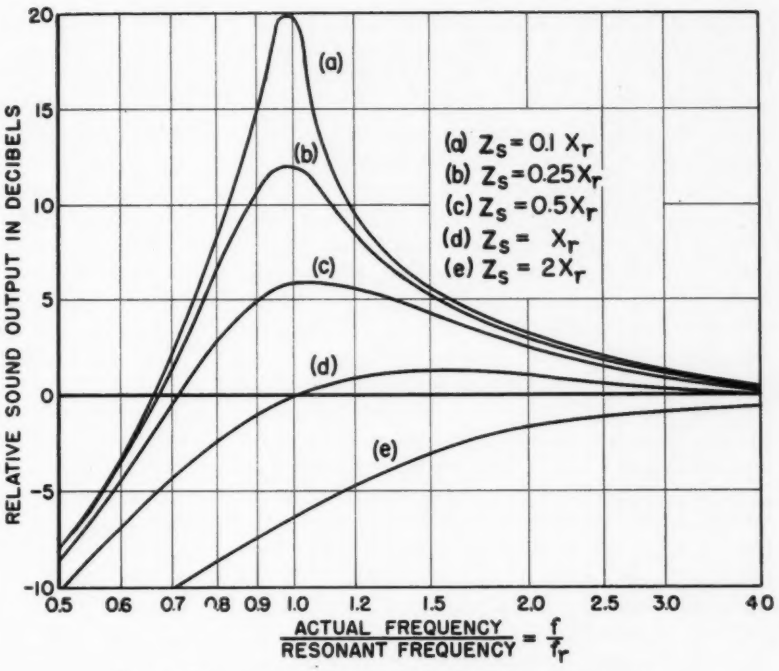


FIG. 5. RELATIVE RESPONSE OF LOUDSPEAKER FOR DIFFERENT VALUES OF DRIVING SOURCE IMPEDANCE

The curves of Fig. 5 indicate how important the impedance $\mathbf{Z}_e$ is in determining the response of loudspeakers. Curve (a) corresponds to a very small value of $\mathbf{Z}_s$, and a mechanical Q of 10 for the speaker. The small value of $\mathbf{Z}_s$ might be the result of either a small value for $\mathbf{B}l$ or a large value of $\mathbf{Z}_e$. It is the type of response encountered, for example, when pentode tubes are used in the driving amplifier and no inverse feedback is employed to reduce the ef-

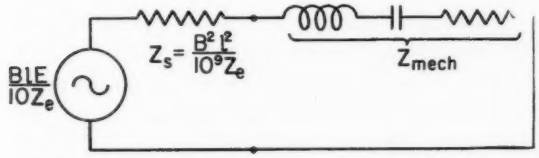


FIG. 4. THEVENIN TRANSFORMATION OF EQUIVALENT CIRCUIT OF LOUDSPEAKER

fective internal impedance. The pronounced peak in the response curve is responsible for the poor reproduction of transients which is sometimes described as "poor speaker damping." The curves make it obvious that for uniform response and clean reproduction of transients the impedance $\mathbf{Z}_s$ should be quite high and, hence, imperative that the effective amplifier driving source impedance $\mathbf{Z}_e$ be low. The fact that triode tubes, when used in the output stage, provide a source of relatively low output impedance is one of the reasons for the traditional preference for triodes. When triodes are used, the load is usually matched to the tubes in such a manner that the impedance looking back into the amplifier from the speaker is approximately equal to the voice-coil resistance. Thus the impedance $\mathbf{Z}_e$ for a triode amplifier is approximately equal to twice the voice-coil resistance. By using pentode of beam tetrode tubes with sufficient negative voltage feedback, it is possible to make the effective output impedance of the amplifier small compared to the voice-coil resistance, and $\mathbf{Z}_e$ can thus be made approximately equal to the voice-coil resistance. In other words, the "speaker damping" of pentodes with sufficient feedback is twice as good as that of triodes without feedback.

The impedance $\mathbf{Z}_e$ is not the only factor affecting the response of speakers. A glance at the expression for $\mathbf{Z}_s$ indicates that the **B** product of the speaker enters into the response characteristic with an importance which is not generally recognized. Since ordinary methods never permit the impedance $\mathbf{Z}_e$ to be reduced below the value of the voice-coil resistance, the maximum value which can be achieved for $\mathbf{Z}_s$ is limited by the value of $\mathbf{B}l$. For speakers with small magnetic structures, this maximum value is still too low to result in appreciable improvement in the response obtained with a very high value of $\mathbf{Z}_e$. Even with speakers having the largest magnetic structures supplied in the standard lines, the maximum value of $\mathbf{Z}_s$ which can be obtained is still considerably below the optimum value for the speaker in an infinite baffle. Thus, curve (c) corresponds closely to the response in an infinite baffle of an eight-inch speaker with a 6.8-ounce Alnico V Magnet and a 3.2-ohm voice coil when driven by an amplifier with negligible internal impedance. Curve (b) corresponds approximately to the response of the same speaker when driven by an amplifier with triodes in the output stage. Thus optimum response, if achieved by conventional methods, apparently requires the use of an amplifier having sufficient negative voltage feedback to reduce the internal impedance to a negligible value, and, in addition, the use of a larger magnet than is obtainable in speakers of moderate cost. Investigation has also revealed that optimum values of $\mathbf{Z}_s$ for other baffles require larger magnetic structures than can be obtained in even the more expensive speakers.

The foregoing discussion indicates that a method for increasing the value of $\mathbf{Z}_s$ which does not require the use of excessively large and expensive magnetic structures would be of considerable value. The remaining portion of this paper outlines such a method.

Optimum response of a speaker in an infinite baffle requires that the impedance $\mathbf{Z}_s$ be equal to X_r. This in turn requires that for most speakers $\mathbf{Z}_e$ be made smaller than the voice-coil resistance. Inspection of Figs. 2 and 3 makes it obvious that negative voltage feedback, applied in the customary fashion, cannot reduce $\mathbf{Z}_e$ below $\mathbf{Z}_{vc}$. In conventional feedback amplifiers the feedback voltage is taken from the point (a) in Fig. 2, and acts to reduce $\mathbf{Z}_i$. As mentioned earlier, $\mathbf{Z}_i$ can be reduced by this means to very low values. If a feedback voltage could be taken, instead, from point (b), or directly across the motional impedance, then $\mathbf{Z}_{vc}$ would be included in the feedback loop along with $\mathbf{Z}_i$, and $\mathbf{Z}_e$ could then be reduced to any desired value. In other words, the feedback voltage must be the same as the motional voltage of the speaker.

The author has accomplished the result mentioned above in a very simple manner by winding a separate feedback coil of very fine wire over the existing voice coil in a conventional speaker. The voltage induced in this coil by motion of the voice-coil structure in the magnetic field of the speaker is a pure motional voltage at most frequencies. This voltage, used as the feedback voltage, permits reducing $\mathbf{Z}_e$ below $\mathbf{Z}_{vc}$. This method has the additional advantage of including non-linearities of the cone suspension in the feedback loop and reducing distortion from this cause. Also, by proper design of the feedback coil, non-linearities due to fringing of the magnetic field are included in the feedback loop and the accompanying distortion is reduced with no loss in magnetic efficiency of the speaker.

At very high audio frequencies some difficulty is caused by the mutual inductance between the driving voice coil and the pickup coil. The mutual inductance produces in the feedback voltage a component which is dependent on the induction between

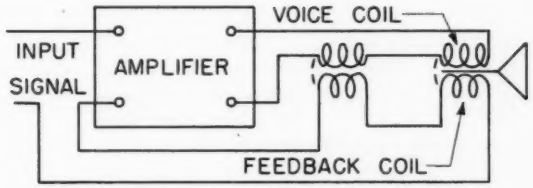


FIG. 6. AMPLIFIER-SPEAKER COMBINATION WITH MOTIONAL FEEDBACK

the coils rather than the motion alone. This voltage of induction is very small at most frequencies but becomes quite large at the higher frequencies, and, unless compensated for, results in the attenuation of the high frequencies. A very simple but effective solution to this difficulty was suggested by the author's colleague, Professor W. Ryland Hill. The difficulty results from mutual inductance between the circuits of the driving voice coil and pickup coil, and is overcome by placing additional mutual inductance of opposite sign between the circuits at a point external to the magnetic field. Voltages of induction which are equal and of opposite sign are produced in the feedback circuit and cancel, leaving a pure motional voltage as the feedback voltage. It is therefore possible to design as a unit an amplifier-speaker combination, such as the one shown in Fig. 6, of superior performance. Table I, which is included for reference, lists for five typical speakers mechanical and magnetic data necessary to such a design.

In summary, the method presented furnished a means of achieving excellent performance from speakers of low cost. The addition of the pickup coil to the voice-coil structure at the time of manufacture should add very little to the cost, and result in negligible change in the mechanical characteristics of the speaker.

TABLE I

MECHANICAL AND MAGNETIC DATA FOR LOUDSPEAKERS

(Note the similarity in the mechanical characteristics of speakers of the same size)

Speaker Type	Diameter (inches)	Magnet	Voice-Coil Resistance (ohms)	Resonant Frequency (cps)	Effective Mass Including Air Load with Baffle (grams)	Compliance of Suspension (cm/dyne)	Mechanical Q	Magnetic Conversion Factor $\frac{B^2l^2}{10^9}$
Cinaud. P8J1	8	6.8 oz Alnico V	6.5	113	9.45	2.1×10^{-7}	15	3.60×10^{4}
G E S810D	8	6.8 oz Alnico V	3.2	115	9.7	1.98×10^{-7}	9.6	1.38×10^{4}
Unknown	8	21 oz Alnico III	6.5	118	9.4	1.93×10^{-7}	18	1.82×10^{4}
Cinaud. P6F1	6	3.16 oz Alnico V	2.95	140	5.50	2.35×10^{-7}	17	6.65×10^{3}
Unknown	6	1.47 oz Alnico V	2.75	136	3.6	3.78×10^{-7}	12	2.12×10^{3}

BRITISH ENGINEER STUDIES NEW BRIDGE

Mr. W. T. F. Austin, civil engineer from the London firm of engineering consultants, Freeman, Fox, and Partners, was a campus visitor during September. Mr. Austin, who is traveling on an E.C.A. scholarship, was primarily interested here in the studies on the stability of suspension bridges being conducted by the Engineering Experiment Station, and in the new Tacoma Narrows Bridge just completed.

Mr. Austin's firm, together with that of Mott, Hay, and Anderson, is charged with the design of two similar suspension bridges, one over the Firth of Forth, the other over the River Severn. The Severn River span will be 3,300 feet in comparison with the 2,800-foot span of the Tacoma Bridge.

Professor F. B. Farquharson, in charge of the Station's bridge research, visited the offices of Freeman, Fox, and Partners in 1946 and has carried on correspondence with the firm in an exchange of data bearing on their mutual interests.

SEPARATION OF SUBSTANCES BY DIALYSIS THROUGH CELLOPHANE MEMBRANES

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The process of dialysis offers a means for partial separation of one soluble substance from another when the two molecular species differ substantially in molecular size and, hence, in their diffusivity. The commercial separation of sodium hydroxide from polysaccharides by dialysis of viscose rayon steep liquors is well known. Also, it has recently been shown[1] in this laboratory that by dialysis of sulfite waste liquors a major proportion of the lignin contained therein can be recovered as non-dialyzable lignin sulfonates of high purity, whereas the low molecular weight sugars and other impurities along with some lignin sulfonates pass through the membrane into the dialyzate.

Rational design of dialysis equipment could presumably be made if it were possible to predict the rate of mass transfer of a soluble substance through a membrane. This rate of mass transfer might be expected to be controlled by three main factors: (1) the coefficient of free diffusion of the substance to be dialyzed, (2) the size, shape, length and frequency of the capillary "holes" through the membrane, and (3) the flow characteristics of the fluids flowing past the two sides of the dialysis membrane. In some cases a fourth factor may be significant, namely, the actual size and shape of the particle to be dialyzed compared to the size of the passages through the membrane; if the particle size is too large compared to the size of the membrane passages, dialysis may not occur at any substantial rate.

The three main factors expected to control the rate of dialysis may be at least approximately evaluated. Measurement of diffusion coefficients can be conducted by several well-known methods and many such results are recorded in the literature. Characterization of the passages in a membrane is possible by methods to be mentioned hereafter. The extensive information now available dealing with fluid mechanics makes possible in simple cases the treatment of the effects of the flow characteristics of the fluids passing the dialysis membrane.

Q. P. Peniston

Thus, in the present work, it has seemed desirable to try to bring together experimental data suitable to test some features of this approach toward a design procedure. Most effort has been applied to correlation of the rates of mass transfer with the diffusivity of the substance undergoing dialysis. Only preliminary information has been developed with respect to the effects of the flow characteristics of the fluids flowing past the membrane.

Membrane Characteristics

The capillary structure of membranes can be estimated from measurements of the membrane thickness, d, the amount of water retained by the wet membrane, W, and the porosity of the membrane P. Such measurements have been carried out by the authors on four cellophane membranes. From these data, by use of the equations of Manegold,[2] the capillary structure of the membranes used in the present work has been estimated[3] with results shown in Table I.

J. L. McCarthy

*Extracted from the thesis submitted by Robert E. Davis in partial fulfillment of the degree of M.S. in Ch.E., 1948.

Determination of Dialysis Rate Coefficients

Glucose, urea, sodium *p*-toluene sulfonate, sucrose and oxalic acid in aqueous solutions were separately dialyzed through each type of membrane.

A membrane was soaked overnight in water, then tied to one end of a cylindrical glass tube eight inches long and two inches in diameter. Strips of rubber were used to prevent leakage. Six such glass tubes with membranes secured to the bottom of each were placed vertically in a wooden support on top of a large jar containing eleven liters of water. Each tube was filled with 100 ml of the solution to be dialyzed. The position of the tubes was adjusted so that the surfaces of the liquids inside and out were at the same level. Stirrers in each tube and in the large jar were operated by a motor to provide essentially constant conditions of agitation. A few drops of toluene were placed in the large jar to prevent attack of the membrane by microorganisms. Each experiment continued at 20 to 21° C for approximately 24 hours.

As dialysis proceeded, samples were periodically extracted and analyzed. Glucose concentrations were determined by means of a polarimeter, oxalic acid concentrations by titration with standard potassium permanganate solution, and the other solute concentrations by evaporation and weighing.

Experimental data were treated by use of the following equation which was taken to describe the dialysis process:

$$R = (h)\ (A)\ (\Delta c) \qquad (1)$$

where R = weight of solute transferred per unit of time, h = over-all solute transfer coefficient, A = membrane area, and Δc = log. mean difference in concentration of solute between solutions on each side of the membrane. Values of h for each solute and each membrane were calculated with results as shown in Table II.

Relations between Over-all Solute Transfer Coefficients, Free Diffusion Coefficients for Solute, and Membrane Characteristics

The total resistance to solute transfer, $1/h$ will be equal to the sum of the three individual resistances, i.e., the "film" resistances on each side of the membrane, and the resistance offered by the membrane itself:

$$1/h = K_1 + 1/\delta + K_3 \qquad (2)$$

where K_1 and K_3 are the resistances of the liquid films on inside and outside of the membrane, and δ is a dialysis rate coefficient for solute transfer through the membrane itself.

The derivation of equations relating δ to the coefficients of free diffusion of the substances dialyzed and the membrane characteristics has been published by Manegold.[4] When a solute diffuses through a water-filled capillary system under equal experimental conditions (concentration difference, volume, dialysis surface, and temperature), the amount transferred per unit of time depends upon the following factors: (1) D, the coefficient of free diffusion; (2) the sum of the cross-sectional areas of all pores per square centimeter of membrane surface, which can be related to W, the water-holding capacity of the membrane; (3) the length of the diffiusion path, which can be related to d, the membrane thickness; (4) the size and shape of the cross section of a single capillary; (5) the size and shape of the diffusing particles; and (6) any interaction between the solute, the solvent, and the membrane. Manegold expresses the dialysis rate coefficient as the following function of the first three parameters:

$$\delta = \frac{K_2 DW}{d}, \qquad (3)$$

TABLE I

CHARACTERISTICS OF CELLOPHANE MEMBRANES[a]

Membrane Number	Membrane Type	Thickness d (cm)	Water Content W	Porosity $(P)(10^7)$ (Sec^{-1})	Pore Structure		Crevice Structure Half width β_2 Å
					Number of Pores (N) (10^{-10}) (cm^{-2}–1)	Radius of Pores r_2 Å	
4	du Pont cellophane 450 PT	0.00597	0.56	9.47	4.0	148	64
2	du Pont cellophane 300 PT	0.00470	0.60	7.47	5.7	129	56
7	Denitrated nitrocellulose No. 30	0.0105	0.46	3.14	4.7	125	54
1	Denitrated nitrocellulose K412	0.0135	0.38	1.77	4.4	117	52

a Detailed experimentation and calculation methods are to be reported elsewhere by the authors.[3]

TABLE II

Over-all Solute Transfer Coefficients

Substance	h = (cm/hr)			
	Membrane 1	Membrane 7	Membrane 4	Membrane 2
Sucrose	0.0743	0.1258	0.205	0.231
p-Toluene sulfonate	0.1822	0.279	0.334	0.337
Glucose	0.1710	0.227	0.356	0.372
Oxalic acid	0.373	0.492	0.673	0.778
Urea	0.440	0.558	0.686	0.900

but he also includes the constant, K_2, to allow for the effects of the latter three factors, which influence transfer in a capillary system but not in free diffusion.

From Eqs (2) and (3), for one substance diffusing through different membranes when film resistances are constant,

$$K_1 + K_3 = \frac{1}{h} - \frac{1}{\delta} + \frac{1}{h} - \frac{d}{K_2 DW} = \text{constant.} \qquad (4)$$

Thus for one particular solute with a characteristic diffusion coefficient, D, dialyzing through different membranes, each with a characteristic thickness, d, and water-holding capacity, W, there may be a specific value of K_2 such that Eq (4) will be satisfied, provided that the three latter factors mentioned above have constant influence. On this basis, appropriate values of K_2 were assumed and used in Eq (4) with the membrane characteristics shown in Table I and with appropriate values for diffusion coefficients* to calculate values of $K_1 + K_3$, the total film resistances, as shown in Table III. It is notable that with three unexplained exceptions, these values come out approximately constant for a particular solute with the four membranes. Thus it appears that assumption of a constant K_2 for a particular solute is justified, at least for the four membranes studied.

The values of K_2 for each solute, which sufficed to satisfy Eq (4) for the experiments with the four membranes, are shown in Table IV, along with free diffusion coefficients and molecular weights for the solutes. Since K_2 may be regarded as related in part to the sieving effect exerted by a membrane on dialyzing molecules, the value of K_2 might be expected to vary inversely with the size of the solute molecules.

*Free diffusion coefficients for urea and sucrose were taken from the International Critical Tables, p. 71; for glucose from Friedman and Carpenter, *J. Am. Chem. Soc.* 61, 1745 (1939); for oxalic acid from Oholm, *Finske Kermistsamfundets Meddelanden* 30, 69 (1921). The diffusion coefficient of sodium *p*-toluene sulfonate was calculated from values of its equivalent conductance given by Bolan and Hope, *J. Chem. Soc.* 843 (1941), by the method of Kolthoff and Lingane, "Polarography," p. 45.

TABLE III

Values of Total Film Resistances Found for the Dialysis of Substances through Different Membranes[a]

Substance	K_1+K_3				Maximum % Deviation from Average for Each Solute
	Membrane 1	Membrane 7	Membrane 4	Membrane 2	
Urea	1.118	1.113	1.132	0.865[b]	1.0
Oxalic acid	0.975	0.922	0.982	0.904	4.3
Glucose	1.630	1.690	1.781	1.755	4.3
p-Toluene sulfonate	2.18	1.43[b]	2.03	2.24	5.6
Sucrose	4.67[b]	2.40	2.38	2.43	1.1

[a] Assuming values of K_2 shown in Table IV.
[b] Not included in computing averages.

Assuming these to be spherical, their cross-sectional area will vary with molecular weight, M, to the two-thirds power. The relation between $1/K_2$ and $M^{2/3}$ is shown in Fig. 1, and for urea, glucose, and sucrose, a nearly linear relation results which can be expressed quite well for the present data by the function,

$$\frac{1}{K_2} = 0.084\ M^{2/3} \qquad (5)$$

where 0.084 = an empirical constant. Deviations observed for oxalic acid and for sodium *p*-toluene sulfonate, may arise because the movement of these ions through membranes is retarded by electrical charges on the surfaces of the capillaries. Hydration effects may also be influential.

Prediction of Separations by Dialysis

The relationships given above may be used to indicate how rough predictions may be made of the possible extent of separations of uncharged and water-soluble substances X and Y by use of batch dialysis, as follows:

1. Knowing the molecular weights of each substance, utilize the type of correlation shown in Fig. 1 to secure values for K_{2X} and K_{2Y}.
2. Knowing the diffusion coefficients, D_X and D_Y, and also the membrane thickness, d, and the water-holding capacity, W, then use K_{2X} and K_{2Y} in Eq 3 to compute the dialysis rate coefficients δ_X and δ_Y.
3. Estimate K_1+K_3 from data of the type given in Table III, then utilize Eq 2 to calculate the over-all solute transfer coefficients, h_X and h_Y.

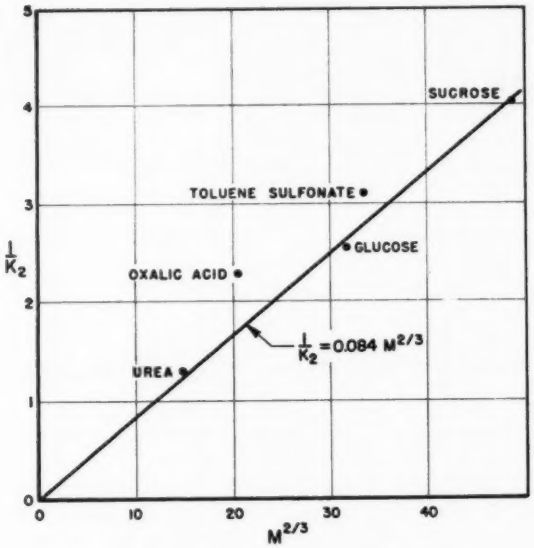

FIG. 1. RELATIONSHIP BETWEEN K_2 AND SOLUTE MOLECULAR WEIGHT, M

4. Knowing for batch dialysis the effective membrane area, A, the time for dialysis θ, and the initial concentration of solutes, C_{0X} and C_{0Y}, the final concentration of each solute, C_X and C_Y can be calculated, using the integrated expression,

$$ln \frac{C_0}{C} = hA\theta. \qquad (6)$$

Comparison of C_X and C_Y obtainable after various periods of dialysis indicates the possible extent of separation and also permits calculation of yields.

For continuous tubular dialyzers individual film resistance data may be readily correlated as indicated by the results of Chisholm[5] working with the authors. He flowed an oxalic acid solution at steady state through a tubular section of membrane with pure water flowing countercurrently in a annular space outside the membrane. Inlet and outlet concentrations of oxalic acid were measured when the flow rate of the oxalic acid solution was held constant and that of water was varied. Treatment of his data may be based on Eq 2 to relate h with the individual outside film resistance, K_3 and the latter can be expressed as

$$K_3 = \frac{1}{kV^{0.8}} \qquad (7)$$

TABLE IV

RELATION BETWEEN K_2 AND SOLUTE MOLECULAR WEIGHT

Substance	Free Diffusion Coefficient D (cm²/hr)	Proportionality Constant K_2	Molecular Weight M	Ratio $\frac{1/K_2}{M^{2/3}}$
Urea	4.26	0.75	60	0.085
Oxalic acid	4.81	0.43	90	0.115
Glucose	2.16	0.39	180	0.080
p-Toluene sulfonate	3.34	0.32	192	0.093
Sucrose	1.662	0.25	342	0.082

where k = constant and V = linear velocity of the fluid.

As shown in Fig. 2, the plot of $1/h$ versus $1/V^{0.8}$ is substantially linear and extrapolation to infinite velocity gives the value of $1/h$ which would be applicable if no outside film resistance existed. Similar treatment of the inside individual film resistance and dimensionless group correlations should provide adequate basis for estimation of total film resistance in continuous tubular dialyzers. To design this type of equipment, a relation of the type of Eq 1 along with an appropriate average concentration gradient would be utilized.

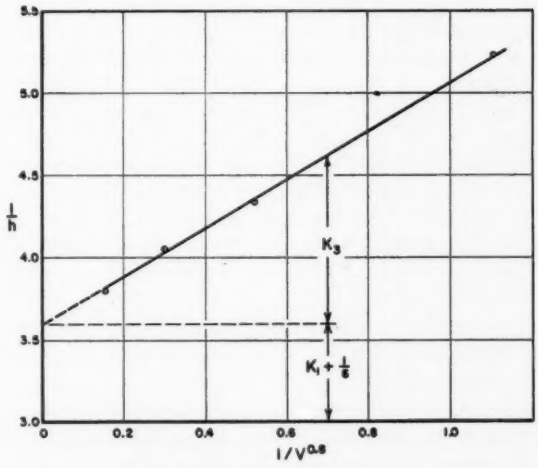

FIG. 2. RELATIONSHIP BETWEEN OVER-ALL SOLUTE TRANSFER COEFFICIENT AND LINEAR VELOCITY OF FLOW OF WATER IN ANNULAR SPACE IN A CONTINUOUS TUBULAR DIALYZER
(Units of h and V are cm/hr.)

Summary

1. Urea, oxalic acid, glucose, sodium *p*-toluene sulfonate, and sucrose in aqueous solutions have been dialyzed under comparable conditions through four cellophane membranes previously characterized as to capillary structure.

2. Dialysis rate coefficients have been calculated and correlated.

3. The prediction of the extent of separation possible by dialysis has been discussed for two solutes.

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3. Davis, R. E., Peniston, Q. P., and McCarthy, J. L., unpublished work, University of Washington.

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Post-Convention Seminar Held For Humanistic-Social Division

At the close of the annual convention of the American Society for Engineering Education held on the University of Washington campus June 23-26, the Department of Humanistic-Social Studies acted as host for the first Summer School held under the auspices of the Humanistic-Social Division of the Society. For three days a group of from thirty to forty delegates attended special meetings devoted to problems and achievements of departments of humanities and social studies in several of the major technical schools of the country.

The main theme of the Summer School meetings was the integration of the teaching of the humanities and social studies with the teaching of the sciences and engineering. The program was approached from two points of view, integration through values and integration through methods of thinking and methods of teaching. The third day was devoted to a presentation and discussion of actual programs of humanistic-social studies now operating in about ten technical colleges.

H. R. Bartlett (Massachusetts Institute of Technology) was chairman of the Friday session which heard J. R. Van Pelt (Batelle Memorial Institute) on "Values Inherent in Engineering," J. R. Naiden (University of Washington) on "Values Inherent in the Humanities," and D. W. Smithburg (Illinois Institute of Technology) on "Values Inherent in the Social Sciences."

Harold Gray (Rensselaer) presided over the Saturday meeting which had as its keynote "Integration Through Methods of Thinking and of Teaching" with A. A. Gilmore (Carnegie Institute of Technology) as the speaker on "Method is the Bond" followed by a panel discussion in which Natalie C. Rupp (University of Washington) suggested approach through "Literature and the Arts," R. M. Boarts (University of Tennessee) through "Engineering," Dell Skeels (University of Washington) "Anthropology," and S. P. Olmsted (Rensselaer) through "Philosophy."

The last session (Monday) featured descriptions of programs now being offered by departments of humanistic-social studies. The following members represented their respective institutions:

A. A. Gilmore, Carnegie Institute of Technology
Natalie C. Rupp, University of Washington
William Huse, California Institute of Technology
H. R. Bartlett, Massachusetts Institute of Technology
Donald Smithburg, Illinois Institute of Technology
Carl Condit, Northwestern University

Dr. S. W. Chapman, head of the Department of Humanistic-Social Studies at the University of Washington, was chairman of the program committee.

Although attendance at the meetings was limited because distance made it impossible for many institutions to send delegates, the purposes of the Summer School were fulfilled. First, the Humanistic-Social Division of the A.S.E.E. gained experience which will help in the running of another larger summer school, perhaps next year. Second, a large number of faculty members in the western section of the country had an opportunity to attend a summer school. Third, a representative group of people interested in problems of humanistic-social education for engineers had an opportunity to get well acquainted, to discuss common problems, and to learn something of the variety of program and commonness of purpose to be found in humanistic-social curricula around the country. About a dozen schools were represented on the actual program of the Summer School and delegates came from institutions from Maine to California, and from North Carolina to Washington. Especially noteworthy was the fact that as many as 25 per cent of the attendance at individual sessions were men from technical rather than humanistic-social faculties.

GLACIAL GEOLOGY OF SEATTLE

J. H. MACKIN
Professor of Geology

D. R. MULLINEAUX
Research Fellow, Engineering Experiment Station

W. J. STARK
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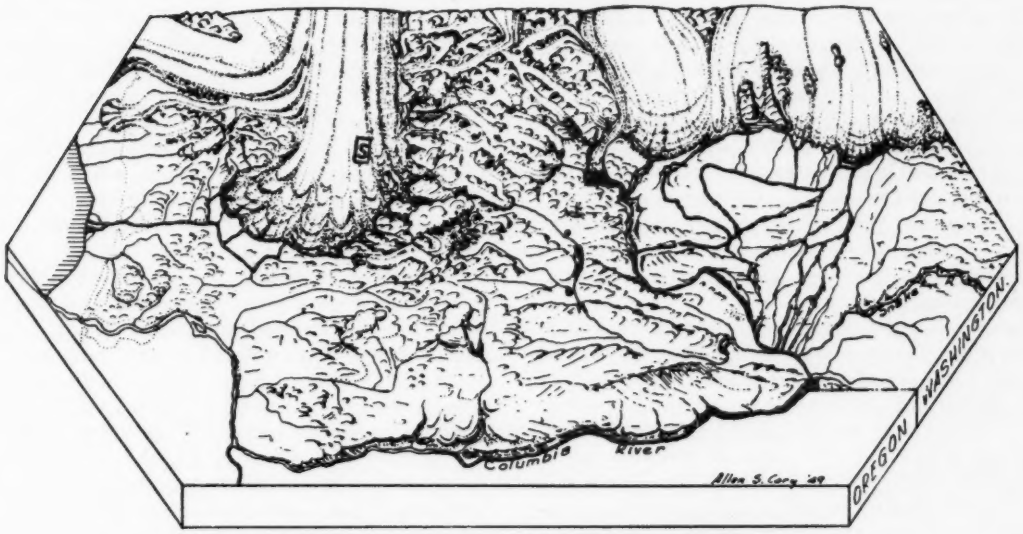

FIG. 1. BLOCK DIAGRAM SHOWING MAXIMUM EXTENT OF GLACIERS IN WASHINGTON DURING THE LAST GLACIAL STAGE
(Rectangle S marks position of Seattle.)
From drawing by Allen S. Cary

THE CITY OF SEATTLE is built on a thick sequence of clay, sand, and gravel deposits formed during the Pleistocene ice age. These materials are of special concern to the engineer because their characteristics play an important part in the planning of landslide control measures, tunneling and excavation operations, and in the design of foundations for all types of structures. If the lithologic units were in a simple and orderly succession the engineer could get satisfactory data for purposes of design by standard drilling and laboratory testing procedures, at a minimum of expense. But the relationships within the glacial succession are actually very complex, and this complexity places a premium on any evidence that might tend to clarify the subsurface picture.

To the geologist, the glacial deposits are of interest from a wholly different point of view that emphasizes their manner of origin and the sequence of events they have recorded. It is reasonable to expect that a knowledge of the geologic relations, even in the most general terms, should provide a basis for efficient planning of exploratory programs, and for interpretation of the data obtained.

For these reasons a geologic study of the glacial deposits of the city was sponsored by the Engineering Experiment Station, in close cooperation with the office of the City Engineer, during the 1949-50 school year. The work was carried on by Mullineaux and Stark under the supervision of Mackin; this summary of the results is written by Mackin because Mullineaux and Stark are engaged in professional geologic work elsewhere in the country. The present brief statement is intended to call attention to the full report, which will be placed on open file in the City Engineer's office.

Figure 1 indicates the position of Seattle with regard to the extent of ice in the Puget lowland during the last glacial stage. The Cascade and Olympic margins of the Puget glacier were about 3,000 feet above sea level in the latitude of Seattle, and it is safe to infer that the ice was at least 3,000 feet thick over the city. The stream-lined Seattle hills,

and the deep troughs of Puget Sound and Lake Washington, were largely shaped by this great mass of southward-flowing ice; the topography formed by the glacier has been modified only by wave cutting, as at Magnolia Bluff, by the partial filling of the troughs, as by the Duwamish River, and by local ravine cutting by smaller streams.

But while the present topography was modeled by the last glacier and has been little changed since its recession, the materials that make up the greater part of the typical Seattle hill were formed during earlier glacial periods that were separated from the last, and from each other, by intervals of time long enough to permit very extensive erosion of the Puget lowland area by streams. The interglacial periods were, in other words, very much longer than the postglacial period. The important point for present purposes is that the hills and valleys of earlier Pleistocene glacial and interglacial periods did not necessarily correspond in position with those of today; a modern Seattle hill may include parts of hills of an earlier generation. The resulting complexity is indicated, diagrammatically, by Fig. 2.

The oldest of the lithologic units is bedrock consisting of sandstone and shale and several types of volcanic rocks. It underlies the whole area but is generally deeply buried, occurring at or near the surface only in a belt that includes Seward Park, Georgetown, and Alki Point. The west-northwesterly trend of this belt of partly buried bedrock hills corresponds with the strike of the strata, and suggests the topographic grain of this part of the Puget lowland previous to the advance of the first Pleistocene glacier. For every engineering purpose, the bedrock is wholly different from the glacial materials that rest on it.

The oldest glacial deposit of which there is any local record is the Beacon till, exposed in a brick pit on the west side of Beacon Hill just south of Spokane Street. It consists of stones of all sizes embedded in a compact clayey matrix, and was deposited directly by ice at the base (rather than at the front) of an actively moving glacier. It is seen only in the pit, where it is overlain by bedded clays of the Duwamish formation.

The Duwamish formation consists of clay and silt with minor peat beds, exposed on both sides of the Duwamish valley from the north end of Beacon Hill to the south city limits. The massive clay phase is best seen in the workings of the Klinker Sand and Gravel Company above West Marginal Way, where it attains a thickness of at least 200 feet. The varved clay phase is exposed in landslide scars on the west side of Beacon Hill west of the Marine Hospital and in adjoining low hills just north of Dearborn Street. The varved clay differs from the massive clay in that it consists of a regular alternation of thin layers of colloidal clay and thicker layers of silty clay; these layers represent the winter and summer deposit, respectively, on the floor of a glacial lake. About 500 of the yearly pairs in a total thickness of about 100 feet of the Duwamish varved clays indicate the duration of this one lake, and the rate of sedimentation on its floor.

Both the massive and varved phases of the Duwamish clays are overlain by beds of clayey silt and sand with interlayered peat. Microscopic study of pollen grains from different levels in the peat indicates a general warming of climate during the existence of the swamp in which the peat accumulated, to produce conditions essentially the same as those of the present time. These relations, together with the fact that the Duwamish clays rest on the Beacon till without evidence of a time break, indicate that the Duwamish formation was deposited during the recession of the glacier that formed the Beacon till.

The type locality of the Klinker till is in the Klinker pit mentioned earlier. The thickness varies from about 15 feet at the type locality to a maximum of about 80 feet in the Abrahamson pit at West Brandon Street and West Marginal Way. The fact that it lies on different members of the Duwamish formation from place to place within the city suggests that the swampy depositional plain of late Duwamish time had been eroded into a hill and valley

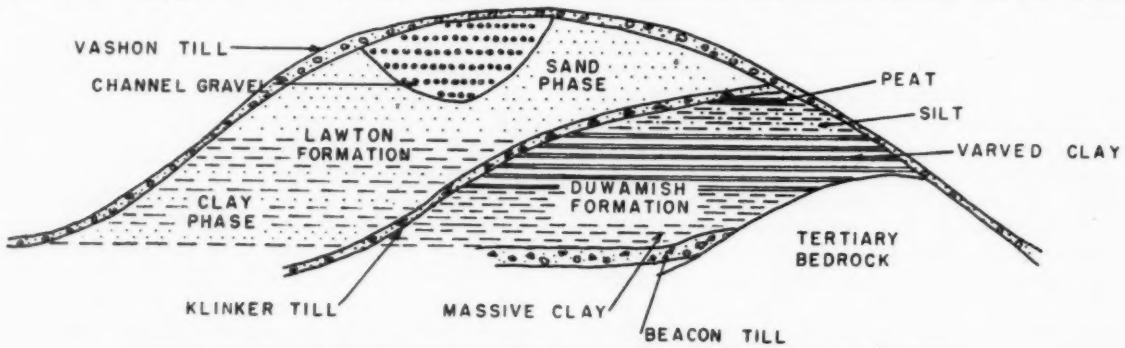

FIG. 2. DIAGRAMMATIC CROSS SECTION SHOWING POSSIBLE COMPLEXITY OF A SEATTLE HILL

topography previous to the advance of the glacier that formed the Klinker till.

The Lawton formation is exposed in sea cliffs in the Fort Lawton area, just south of West Point, where the thickness is at least 250 feet with the base below sea level. The clay phase, with interbeds of sand in the lower part, grades upward at 150-160 feet into coarse sand that forms the upper part of the unit. The Lawton is the most extensive of the major depositional units predating the last glacial stage, and it is, in general, remarkably uniform in lithology throughout the area studied. The gradational contact between the clay and sand phases, critical for engineering purposes, varies from about 125 to 275 feet above sea level in different parts of the city.

It is possible that the Lawton sediments were deposited during recession of the glacier that deposited the Klinker till, thus repeating the Beacon-Duwamish relationship, but the evidence at hand does not establish this point.

Coarse gravels, resting on the Lawton sand, occur at several localities within the city. They are evidently the channel deposits of vigorous streams, but it is not certain whether they were formed (1) late in Lawton time, or (2) during the advance of the Vashon glacier.

The Vashon till, named for Vashon Island where it was first described, was spread as a more or less continuous mantle over the Seattle area by the last of the Pleistocene glaciers, probably after deep dissection of all of the earlier deposits. The till sheet varies from a few feet to more than 100 feet in thickness, and occurs at or near the surface except where it has been removed by wave or river cutting or artificial excavation. It is usually, like the earlier tills, a compact, concrete-like material with stones in a matrix of sandy clay, but the characteristics of the till vary with the nature of the underlying material and, where it rests on extensive deposits of Lawton sand, it may consist largely of rumpled sand.

Each of these units is described in detail in the Engineering Experiment Station report, and their extent within the city limits is represented on maps and cross sections. The maps and sections are based on scattered exposures and on geologic interpretations that are in some instances quite uncertain; they are, at best, only approximations of the actual relationships. Their value lies in the fact that they provide, for the first time, a unified picture of the geology of the city, and, at the same time, a natural framework on which quantitative studies of the engineering characteristics of the glacial deposits can be based. The report is, in other words, merely a start in the right direction; it will become increasingly valuable if it is continuously modified and refined as to detail as new data become available.

NOTE: Arrangements are being made with Mr. Ralph W. Finke, Seattle City Engineer, to place the original copy of the complete report, upon which the foregoing article is based, on file in his office. If sufficient interest in this study is shown during subsequent months, publication of a printed edition, including the large number of maps, will be considered.—*Ed.*

PACIFIC NORTHWEST INDUSTRIAL RESEARCH CONFERENCE

The first annual Pacific Northwest Industrial Research Conference was held in Portland, September 18. Sponsored by Raw Materials Survey, Inc., Industrial Managers' Group, the Portland Chamber of Commerce, and other Pacific Northwest Chambers of Commerce, the conference was "conceived to explain both the benefits and limitations of industrial research, and to acquaint executives with the existing research facilities of the area."

Dr. S. E. Maddigan, Director of the British Columbia Research Council, presided over the morning session which featured talks by Dr. J. E. Hobson, Director of the Stanford Research Institute, on "Definition of the Fields of Industrial Research," Dr. W. A. LaLande, Jr., Manager of Research Development of the Pennsylvania Salt Manufacturing Company, on "Does Industrial Research Pay?", and Mr. C. C. Heritage, Technical Director of the Weyerhauser Timber Company, on "Translating Results of Research into Actual Production."

Dr. M. E. Spaght, President of the Shell Development Company, was the luncheon speaker on "Industrial Research in America's Future."

The afternoon session under the chairmanship of Dr. George Gleeson, Dean of the School of Engineering, Oregon State College, reviewed research facilities in the Pacific Northwest. Representatives from the federal government, trade associations, state bodies, colleges and universities, private institutions (American Council of Commercial Laboratories), and research institutes, took part in the discussion. The University of Idaho, Oregon State College, University of Washington, Washington State College, and other institutions were included. Professor F. B. Farquharson, Director of the Engineering Experiment Station, represented the University of Washington.

Such a meeting, in recognizing the vital importance of research, may prove a turning point in the development of this area and mark its transition from a pioneer economy to a modern industrial order.

HOW METALS FRACTURE*

MOST DANGEROUS FRACTURES in engineering service are those occurring unexpectedly in a material which is ductile by ordinary standards and might therefore be expected to deform plastically rather than break at points of high-stress concentration. Fracture by fatigue is an example of such a failure. Another is the so-called brittle fracture of iron and mild steel, particularly at low temperatures, which has been known and has received spasmodic investigation on several occasions, without any rational explanation being found. This type of brittleness has recently come to the fore as a result of spectacular fractures in certain all-welded ships.

There are three ways in which fracture is known to take place in metal crystals:

1. The fracture plane may be crystallographically the same as the plane of shear. The angle which this plane makes with the direction of the principal tensile stress is generally between 40 and 50 deg, but depends upon the orientation of the crystal and the amount of deformation before fracture.

2. There is no well-defined plane, but a wedge is formed by two shear planes making equal angles with the direction of the principal tensile to stress, or, if more planes participate, the crystal may draw down almost to a point.

3. The fracture plane may be crystallographically different from possible glide planes.

The chief difference between 1 and 3 is the amount of distortion which takes place during the actual partition. Thus, the fracture plane may be roughened and have a mat surface or appear bright and polished. If the latter, as is generally the case in 3, the fracture is described as cleavage.

It has been known for a long time that a tendency towards cleavage fracture in an iron increases as the temperature falls. The change in commercial steels may be gradual or sudden. Even if there is a range of 40 C, the change in mechanical properties as measured by rise in yield and ultimate stresses only amounts to a few per cent, and there is no measurable decrease in ductility. Hence, an increase in resistance to shear due to fall in temperature does not of itself appear sufficient to account for the change observed, and in fact, neighboring crystals in the same section are observed to fracture or deform.

Not only does the temperature decide whether a crystal shall deform by shear or fracture, but the orientation of the grains in a polycrystalline aggregate relative to the tensile stress and to each other may also be a determining factor.

The appearance of the fracture of the poly-crystalline aggregate reflects the mode of fracture of the individual grains. The fracture may be wholly made up of types 1 and 2, when the appearance is silky or fibrous, or a certain proportion of the grains may crack and break with little or no distortion. Thus both forms of fracture occur in the same sample. The proportion of each type in a fracture determines the energy absorbed in its propagation as well as the velocity of propagation. The change in fracture does not always follow the energy absorbed in impact, as often a large proportion of the total recorded in such tests is absorbed before fracture begins. Where the measurements of the energy to propagate a fracture have been made, there is a close relation to the type of fracture.

Although most of the cracks appear in the ferrite, numerous examples of their running through adjacent pearlite have been encountered. Groups of ferrite grains frequently have very similar orientations. This is evident from the indictness of the intervening boundaries and fractures may be seen to run across such groups with little change of direction. If such zones are favorably placed for the development of cleavage fractures they may contribute towards the easy initiation of such fractures and a heat-treatment which tends to produce groups of similarly oriented ferrite grains is clearly undesirable. A few isolated grains or groups of grains breaking in a brittle manner are often visible in an otherwise typically fibrous fracture.

Most service fractures have been traced back to some sort of notch. Fractures made in the laboratory have been started by the introduction of a notch perpendicular to the applied stress. The metal at the base of the notch yields at a mean stress, which agrees with that predicted from measurements of the stress concentration factor determined in an exactly similar test piece of cast polyester resin by photoelastic means. Whatever the type of fracture there is always a plastic zone at the notch bottom, and in a normal fibrous fracture, it propagates at the mean breaking stress of the unnotched tensile test piece.

Thus, the metal at the base of the notch can be regarded as passing through all the stages that a

*Foreign abstract from "The Fracture of Metals" by C. F. Tipper, *Metallurgia* (British), January, 1949. Reprinted by permission from *Product Engineer*, April, 1950.

test-piece of very short gage length would pass through from yield to fracture. The machined notch ensures that the mean path of the natural crack is at 90 deg to the direction of loading. A notch at 45 deg does not lead to a brittle fracture under the same conditions of test. As soon as the natural crack has formed, the shape of the original notch loses significance. A notch also ensures a relatively high rate of strain even under static loading, and this increases when the natural crack with its small radius at the end is formed. Although cleavage cracks form under static loads, they are more readily produced under impact.

Fracture is first visible in the center of the notch bottom often by the opening of a crack along a line of inclusions. The main fracture front is thus always ahead of fracture of the surface of a plate, to an extent which varies with the material, the thickness of the plate and temperature of test. This shape persists at distances far removed from the original notch. There is nothing essentially different from the sequence of fracture in a round bar in tension shown to start in the center. Although in the round bar it is very difficult to arrest the fracture at different stages, these stages can be studied in reverse order in the same specimen by cutting sections through an arrested fracture in a plate.

The ends of less brittle and fibrous fractures, and sections through numerous brittle fractures, have also been investigated. In front of the advancing crack on the surface is a zone plastically deformed which is very small in brittle fractures, but may be spread over the whole plate in the most ductile. Sections through this zone enable the depth to which the center has broken to be determined. The outline of the separated parts is irregular and finally consists of holes separated by unbroken metal. Some of the holes are formed by the cracking of a crystal or a group of crystals and their separation by subsequent deformation of the unbroken metal. Thus, on the fractured surface, troughs alternate with ridges, giving rise to the chevron pattern so characteristic of many of these fractures.

While the fracture of ductile material cannot be explained in quite the same way, separation along lines of inclusions can also divide the section into groups of crystals, each one of which may be regarded as a separate tensile test-piece which can deform by shear far easier when freed from transverse restraint. In both types, the holes are finally joined by fine cracks and the fracture is complete.

The influence of structure on mechanical properties, apart from composition is shown by the lower values for elongation and especially, reduction in area in a tensile test and the energy absorbed in impact tests when the test-pieces are cut across the direction of rolling. Since inclusions are elongated by the working they are more dangerous when they are placed with their long axes perpendicular to the principal tensile stress. In this position also, there are more "ways through" for the advancing fracture of whatever type. Cracks meeting an inclusion or hole may be diverted or stopped if the discontinuity affords relief of stress.

These observations refer chiefly to the fracture of mild steel, but they can be applied to explain the fracture of all poly-crystalline aggregates.

CITY PLANNING EXPERT TO LECTURE

F. J. Osborn, lecturer, author, expert on city planning, and founder of Welwyn Garden City, will speak on "Town Planning in England" the evening of November 6, on the University campus.

Mr. Osborn, who is sponsored nationally by the American Institute of Planners, is being brought to Seattle under the auspices of the Pacific Northwest chapter of that organization, the Planning Association of Washington, and the University Office of Lectures and Concerts.

Welwyn Garden City, built as a direct outcome of Mr. Osborn's first book, *New Towns After the War,* was established in 1919 and from that time to 1936 Mr. Osborn served as its estate manager. Since 1936 he has been finance director of a radio manufacturing firm in Welwyn as well as being actively engaged in a national campaign for a new planning policy covering all aspects of town planning, with emphasis on dispersal of people and industry from congested cities to new towns. This policy has rapidly gained acceptance since the air raids of 1940-41, and legislation 1943-47 has transformed planning aims and methods in England. Mr. Osborn's main experience has been on the business side of housing and town building.

Following his first book, which was reprinted in 1942, he was the author of "Transport, Town Development and Industry" (1934), "Overture to Planning" (1941), "The Land and Planning" (1942), and "Green Belt Cities" (1946).

Politically, Mr. Osborn states that he is a "middle of the road planner" and that he believes "by intelligent government control and taxation policy the good life can be promoted without totalitarianism or destroying the scope of free enterprises."

Inquiries may be sent to E. M. Horwood, More Hall, University of Washington.

SHEATHING PAPER AS A CAUSAL AGENT IN PAINT FAILURES

BROR L. GRONDAL
Professor of Forest Products

B. L. Grondal

Unusually severe climatic conditions prevailed in western Washington during the winter of 1949-1950. Snowfalls and prolonged freezing temperatures, seldom encountered in this region, damaged crops, trees and other vegetation as well as roads, highways and masonry. An incidental, but expensive accompaniment of this weather was a substantial increase in the number of paint failures on the wood siding and trim of residences. This focused attention upon the trouble, and a series of newspaper articles in a Seattle newspaper[1] gave wide publicity to paint failures that had occurred very recently.

A cursory investigation during the severe winter weather mentioned above suggested the possibility of paint damage. Gutters and downspouts became filled with ice. When thawing weather finally arrived, many gutters overflowed, spilling water directly upon the siding of houses and, in many instances, leaked into spaces behind siding. Interiors of some houses were damaged by water.

Many householders, recalling the necessity for frequent repainting of siding, came to the conclusion that available exterior paints had deteriorated in quality, and that paint manufacturers had, in recent years, supplied paints in which poor substitutes for linseed oil and white lead had been incorporated. However, as the art of paint manufacture has advanced rapidly, such accusations against manufacturers are not valid. Moreover, paint failures where "good old-fashioned lead and oil" had been used were apparently as numerous as where improved, longer-lived paints had been applied.

The paint failures that have caused most of the trouble that agitates homeowners in western Washington consist of blisters and peeling. Less pronounced failures, such as washing, chalking, alligatoring and crazing are not as apparent to the casual observer.

In an address[2] before the Washington State Council of the Painting and Decorating Contractors of America, delivered in the spring of 1948, the writer discussed, in some detail, the subject of paint blistering. Painting contractors were reminded that blistering was important to them because they had to bear the cost of repainting, and that the nuisance involved was charged against them. The basic reasons for the increase in blistering and peeling of paint were pointed out and the statement was made that "we must find proof to lay before architects and builders so that errors in construction that cause blistering will not be made, repeatedly." It was proposed that a committee be appointed to consider means of financing a study of paint blistering, and such a committee was duly chosen. However, as no

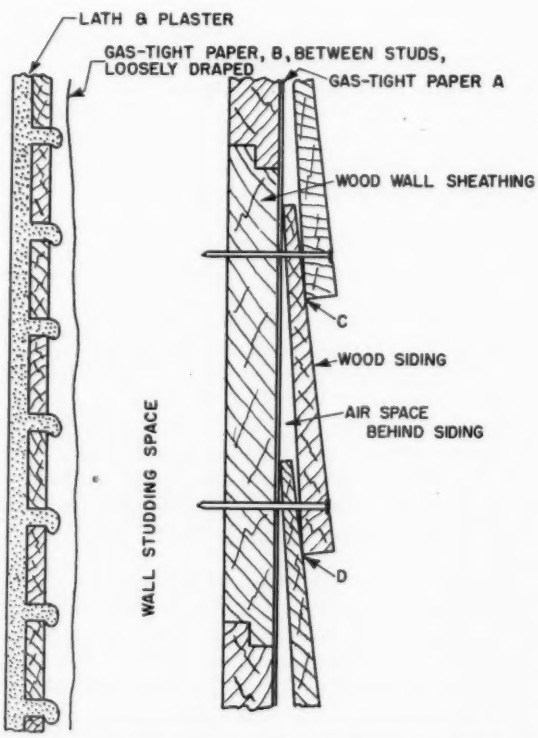

FIG. 1. CROSS SECTION OF TYPICAL STUDDING WALL WITH SIDING EXTERIOR

funds became available for practical field studies, the committee remained inactive.

Before the winter of 1949-1950, in an article[3] which appeared in a trade journal in Ohio, the writer again discussed the subject of paint blisters. This article was reprinted by a trade association, and was widely distributed. Apparently as a result of this article, several "wall ventilators" appeared on the market, and in some instances, according to private communications to the writer, these have averted paint failures on houses where such failures had recurred with annoying frequency.

During the summer months of 1932, 1933, 1934 and 1935, in a series of lecture tours which enabled the writer to visit every state in the Union, he conducted a study of paint failures on wood sidewall materials. As a result of this investigation the following statement was incorporated in a handbook[4] which was written in 1935 for the users of western red cedar shingles: "Paraffin or 'asphalt' saturated paper should *never* be applied to the roof deck before the shingles are laid. If added insulation is wanted, or if it seems desirable to insure against air infiltration, the roof deck may be covered with rosin-sized building paper, dry or 'unsaturated deadening' felt or light-weight 'blue' wallboard. . . . On side walls, before the shingles are applied, the application of a good grade of rosin-sized building paper on the sheathing is highly recommended."

In 1933, Browne,[5] at the U. S. Forest Products Laboratory at Madison, Wisconsin, made the following observation: "As a rule, paint lasts somewhat longer on houses than it does on the south side of a test fence because few houses are as fully exposed to sunshine as a properly located test fence. Some houses will be found in nearly every community, however, on which paint not only fails more rapidly but fails in a very different manner from what it does on test fences. Such failure may become noticeable within a few months after painting and become pronounced within a year. In typical cases the first abnormal development is blistering but the houseowner rarely makes complaint at that stage and may never notice that it has occurred. Later on, the paint cracks and comes off in conspicuous scales whose size and shape bear no relation to the bands of summerwood beneath. Houseowners' complaints are usually made after this stage has been reached, when the surface not only presents a disreputable appearance but is very difficult to repaint properly. Abnormal paint failure of this kind is caused by moisture collecting behind the painted boards during the season when the interior of the house is kept at a materially higher temperature than prevails out of doors. *The source of the moisture may be leaking joints of one kind or another or condensation from air within the hollow side walls when the air is chilled below its dew point.*"*

This abnormal paint failure, regarded as exceptional behavior of paint on some houses previous to 1933, is the type that is so common today. In 1934, Browne[6] made the further observation that "all linseed oil paints, good, bad, and indifferent, are subject to moisture failures if the causative conditions arise. To be sure, pure white-lead paint escapes relatively unscathed under moderately severe conditions that prove disastrous to all other paints but if the conditions are bad enough, white lead fails also. The only certain cure for moisture failures is to eliminate the moisture. In new buildings the moisture may get into the sidewalls when improper methods are followed in drying the plaster. A second source of moisture is open joints or inadequate flashing around windows, chimneys, dormer, eaves troughs, or other junctions in the construction. *A third source of moisture, often the most difficult to remedy is sweating or condensation within the side walls during cold weather.*"*

In 1935, Browne[7] suggested that "when a home is found on which hard types of paint have failed because of moisture and no practicable means are discovered for making sure that the side walls will remain dry in the future the safest procedure to recommend for repainting is to remove all of the old coating and to repaint with a 'soft' paint." White lead is regarded as a "soft" paint.

Mr. Browne has been quoted so extensively because as Senior Chemist at the U. S. Forest Products Laboratory, he has conducted extensive studies on the durability of paint. However, while correct in his conclusions regarding the effect of moisture upon coatings, he does not, in the writer's opinion, indicate clearly why moisture collects *in the siding* of the many houses that today are subject to "abnormal paint failures," characterized initially by blistering.

Previous to 1931, relatively few houses that were painted properly developed blisters and subsequent peeling of paint. Today, this trouble is commonplace. Is it caused by the "improvement" in paint formulations, or were the old-time "lead and oil" or "lead zinc and oil" paints superior to those used today? The writer is of the opinion that the quality of paint, in general, has improved. Yet, blistering has increased.

Two factors that have contributed to paint failures in recent years include (a) thermostatically controlled heating plants, and (b) basic changes in constructional details of modern houses.

The strong trend toward the elimination of overhanging eaves and the application of paraffin-sized or asphalt-saturated paper over the sheathing of

* Italics by present writer.

houses, immediately under the siding, are the two basic changes in construction that have caused a phenomenal increase in paint blistering on houses in which thermostatically controlled heating plants are used.

Teesdale,[8] in discussing the problem of condensation in walls and attics, found that much of the condensation within the walls resulted from the escape of water vapor through the interior or "warm" side of the wall, and therefore came to the conclusion that building paper of the vapor-resistant type should be applied only on the studding immediately behind the plaster or other interior wall material, and that "paper when used outside of the sheathing should be water resistant but not very vapor resistant so that the small amount of water vapor that may leak through the (inner) barrier can escape outward. Slaters felt meets this requirement. Quite possibly the sheathing paper could be omitted entirely; it is conceivable that the omission would result in a drier wall."

In a subsequent publication[9] Teesdale again recommended that any sheathing paper (applied between the siding and the sheathing) should be water resistant, but permeable to vapor.

The fact that in almost every instance where paint blistering has developed over large areas of siding (excepting those instances where successive coats of paint were "incompatible"), the vapor-resistant paper under the siding is periodically covered with droplets of water resulting from the condensation of moisture, has generally escaped attention. In a personal discussion, Mr. Teesdale asserted that this was due to wind-driven rain water, or was due to leakage of water into the space between the siding and the vapor-resistant paper, and that the translocation of this water either by gravity or by revaporization and condensation explained this phenomenon. That the siding often increases in moisture content until paint blistering occurs, when vapor-resistant paper is used over the sheathing cannot, however, be denied.

In the Pacific Northwest, western red cedar *(Thuja plicata)* is the preferred wood for bevel siding. In a recent publication[10] Browne places the cedars, bald cypress and redwood in the first group among five groups as being best from the standpoint of paint-holding characteristics. He also emphasizes a well-known truism that "paints last longest on wood that has been well seasoned but which has regained some moisture so that its moisture content is 12 to 15 per cent. . . . wet wood, the moisture content of which is over 25 per cent, is in an uncertain condition for painting because there is grave danger of failure of the coating by blistering and peeling."

Gunnette,[11] in discussing the condensation of water vapor within walls, further emphasizes that any vapor barrier must be applied on the warm side of the wall, and states that "this latter is contradictory to the usual practice of applying a building paper between the sheathing and the exterior surfacing material of a building. The answer to this is that for many years we have been designing buildings wrongly —and are still doing it, except of course, in some instances where the outside of the wall is the warm side."

Condensation, therefore, from whatever source, that will increase the moisture content of the siding to the "fiber-saturation point," is very likely to produce paint blisters.

Reference to Fig. 1, a cross section of a typical wall, illustrates the incorrect and correct placing of "gas-tight" or vapor-resistant building paper. Such paper behind the plaster, at "B," will serve as a vapor barrier at the "warm" side of the wall. When placed behind the siding, over the sheathing, at "A," this paper will act as a condenser when the temperature of the interior of the house is materially lowered at night and the steady flow of heat through the wall section is materially reduced. As the exterior of the wall cools, air at comparatively high humidity enters into the spaces left between the siding and the vapor-resistant paper, usually through small cracks at "C" and "D." By drilling holes through siding on a typical house, making it possible to insert wet- and dry-bulb thermometers into the space behind the siding, the writer has noted that the dew point is often reached in this space at times, even during the summer months, and that the resulting condensation of water vapor causes a very substantial increase, up to the fiber-saturation point (as determined by an electrical moisture meter) whenever climatic conditions (i.e., low out-door temperatures, but above the freezing point, and high relative humidities) are favorable for this phenomenon to occur. These atmospheric conditions develop frequently, and are not confined to western Washington. It seems reasonable, in view of the overwhelming evidence that has accumulated, that the paper manufacturers should produce a paper of "sheathing grade" that exhibits very low vapor resistance, but which will prevent *rapid* infiltration of air. Asphalt-saturated or "vapor-resistant" papers should be used only on the "warm side" of the wall. As insulating materials are used in the wall sections of many houses, this matter is becoming of increasing importance. When "loose fill" insulation is placed in a wall, the condensation of water vapor in the insulation may create a very serious situation from the standpoint of decay.When such insulation is used in conjunction with a vapor barrier of paper at "A" and "B," the avoidance of paint blistering is only a remote possibility.

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11. Gunnette, Elmer E., "Condensation Within Walls," paper presented at Nat. Eng. Conf., sponsored by the Am. Institute of Steel Construction, 1950.

"The work of A. N. Whitehead and B. Russell has led to a new understanding of the philosophy of mathematics out of which have arisen several schools of thought. In one school it is held, as Russell has taught, that mathematics is fundamentally a branch of logic: another school asserts that logic is part of mathematics. Here appears a flat contradiction, yet in each case the conclusion has been reached by careful and exhaustive analysis. A further examination of the fundamental assumptions of mathematics and of logic may some day disclose a principle of duality in a larger context, no longer within mathematics itself but including mathematics and logic as dual aspects of a richer reality."

—H. W. Turnbull: "Commentary: Mathematics in the Larger Context," *Research,* 3, 5 (May, 1950).

Engineering Research Dividends

Recent theses for advanced degrees, which were submitted as reports on Engineering Experiment Station research projects, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station.

GILARDI, R. C., "A Study of the Utilization of Oyster Shell in the State of Washington." M. S. in Chemical Engineering, 1948.

In addition to a study of the present utilization of oyster shell, experimental firing of shell to produce a high-grade lime and carbon dioxide was carried on. The annual surplus of shell in Washington is approximately 5,000 tons, which would produce about 2,500 tons of lime. An investigation of the chemical composition of the shell failed to show a significant difference in composition of eastern and western oyster shell. In 1947, estimated shell production was 14,500 tons, of which 6,500 tons were ground for poultry use, 5,000 tons were surplus, and 3,000 tons were used for clutch and for road materials. Stockpiles were estimated to contain 12,000 tons. In 1948, production of shell was estimated to be 19,400 tons, of which 15,800 tons were ground for poultry use, and 3,600 tons were surplus. Stockpiles were reduced to an estimated 6,300 tons. The experimental firing data and product analyses show that lime containing 95 per cent or more calcium as calcium oxide can be consistently produced.

STORDALEN, K. N., "The Effect of Fiber Length Upon the Strength of Hardboard." Master of Forestry, 1950.

A series of hardboard specimens were produced in which the only variable was the length of the mechanically produced cottonwood fiber 17/1,000 in. wide and 10/1,000 in. thick. Three increments of length of fiber 1/4-in., 1/2-in., and 3/4-in. were used, and the samples were subjected to bending and tensile tests. On both these tests, panels made from 3/4-in. long fiber bundles showed considerably higher strength than those made from shorter bundles, the arithmetic mean maximum load in bending for 1/4-in. fiber being 11.99 lb and for 3/4-in. fiber, 16.21 lb. In tension, the arithmetic mean tensile strength from 1/4-in. fiber bundles was 1,358 psi and from 3/4-in., 1,923 psi.

JOHNSON, H. A., "Investigation of Effects of Various Amounts of Cerium on the Graphite Formation of Alloy Cast Iron." M. S. in Metallurgical Engineering, 1950.

A study was made of the change in microstructure and tensile strength of a specific cast iron, Carcoloy, produced by the Pacific Car and Foundry Company, as a result of the addition of cerium and silicon. The highest tensile strengths were obtained in the range of 0.04 to 0.05 per cent cerium additions, with 1.0 to 1.2 per cent silicon added as a secondary inoculant of ferrosilicon. Additions in this range produced an improvement of 125 to 150 per cent in tensile strength. Nodular graphite structures were obtained in the alloy cast iron studied, but at the expense of modifying the acicular pearlite matrix.

McLAUGHLIN, W. L., "Deflection of a Cantilever Triangular Plate Under Uniform Normal Pressure." M. S. in Aeronautical Engineering, 1950.

The problem solved here is for the deflection of a cantilever plate with a triangular planform. The solution is for an isosceles triangle with an angle of 90° at the unsupported tip. It is assumed that the loading is constant over the upper surface, and that deflections will always remain small. The solution obtained satisfies the boundary conditions along the free edges, and the condition of zero deflection along the supported edge. The boundary condition on the slope along the supported edge is partially relaxed, however, and the solution presented satisfies this modified condition. The biharmonic plate equation is satisfied identically by using a value of 1/3 for Poisson's ratio. The solution is then extended by empirical methods to a plate which has a fully clamped edge. The results of the extended theory for complete restraint on the supported edge are then plotted, together with the results from the test program. It is shown that good agreement with test results has been achieved.

Notes and Comments

ENGINEERS IN THE NEWS

R. G. TYLER, Professor of Sanitary Engineering, and **W. MASKE,** Sanitary Chemist in the Department of Civil Engineering, flew to Fairbanks, Alaska, September 25 to conduct tests on the municipal water supply.

G. S. SMITH, Professor of Electrical Engineering, read a paper on "The Heat Pump in Residential Heating" before the Northwest Public Power Association on September 14 at Portland, Oregon.

The first progress report on the Navy-sponsored project on "Welded Reinforcement of Openings in Structural Steel Members" was submitted in August to the Navy Department by **R. A. HECHTMAN,** supervisor of the project.

ROBERT E. DAVIS, whose article appears in this issue, has completed work for his Ph.D. in Chemical Engineering and is employed by the Aerojet Engineering Corporation at Azusa, California.

KENDALL L. C. SU, who held an Engineering Experiment Station research fellowship in electrical engineering during the past year, has accepted a teaching fellowship at Georgia Institute of Technology.

K. T. CHANG, Research Fellow in the Engineering Experiment Station on the suspension-bridge project, who received his M.S. in Civil Engineering, will continue work toward his doctorate under a fellowship at Stanford University.

H. A. COOMBS, Professor of Geology, has returned from a three-month trip to Japan where he conducted an investigation of dam sites. The project was sponsored by the Natural Resources Section, General Headquarters of the Supreme Commander of the Allied Powers.

The author of the recently published Report No. 6, "The Chemical Utilization of the Subbituminous Coals of Washington," **L. A. CONRADI,** who was a research assistant in the Engineering Experiment Station last year, has returned to Norway, following some weeks' investigation of coal processing in Pittsburgh, Pennsylvania.

NEW PUBLICATIONS

Bulletin 116. *Aerodynamic Stability of Suspension Bridges,* Part II: "Mathematical Analyses," Frederick C. Smith and George S. Vincent, 63 pp., 1950.

Report No. 6. *The Chemical Utilization of the Subbituminous Coals of Washington,* L. A. Conradi, with Foreword by H. K. Benson, 84 pp., 1950.

Reprint No. 30. "A Simplified Method of Differentiating and Evaluating Functions Represented by Fourier Series," A. M. Winslow, *Quart. of App. Mathem.,* Vol. VII, No. 4 (Jan., 1950).

Reprint No. 31. "Lignin III. Fractional Precipitation of Barium Lignin Sulfonates from Water by Ethanol," Aaron E. Markham, Quinton P. Peniston, Joseph L. McCarthy, *Jour. Am. Chem. Soc.,* **71,** 3599 (1949).

Reprint No. 32. "Behavior of Refractory Oxides and Metals, Above and in Combination, in Vacuo at High Temperatures," Peter D. Johnson, *Jour. Am. Cera. Soc.,* May, 1950.

Reprint No. 33. "Disposal of Sewage into Tidal Waters," Richard G. Tyler, *Sew. and Ind. Wastes,* Vol. 22, No. 5 (May, 1950).

Reprint No. 34. "Thermal Conductivity of Soils for Design of Heat Pump Installations," George S. Smith and Thomas Yamauchi, *Heating, Piping & Air Conditioning,* July, 1950.

Reprint No. 35. "Applications of Thevenin's Theorem to Direct Current Motor Analysis," Walter E. Rogers, *Jour, Eng. Ed.,* June, 1950.

WATER INJECTION IN A SMALL JET ENGINE

(Continued from page 7)

No adjustable jet cone would be required, and the decreases in exhaust temperatures should be small. This seems to be the only practical type of injection at the present time that can be applied directly to existing units.

In two cases in which temporary increases in output are required, water injection is a solution. The first is that of a military plane in combat. Increased thrust when water is injected into the compressor unit of a turbojet engine due to evaporation cooling has been observed at the NACA laboratories and may be employed in combat planes.* The second is that of certain types of take-off situations, such as those involving heavily loaded planes or restricted runway lengths.

Post-combustion injection, could not, on the basis of these experimental results, be applied favorably to existing power units since thrust increases could be effected only in plants designed to operate with this type of injection. However, if a plant were designed with proper cooling provisions and an adjustable jet cone, even higher thrust increases could be expected from this type of injection than from precompression injection.

*Newark *Evening News,* July 28, 1950, p. 17, via *Technical Survey,* August 5, 1950.

PUBLICATIONS
of the
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF WASHINGTON

Requests for copies of publications should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.
All publications are free on request.

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48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris. 35 pp. 1928.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred Scoville Eastman. 20 pp. 1931.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Harris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
60. An Electromagnetic Balance for Force Measurement of Current Control. Fred Scoville Eastman. 29 pp. 1932.
61. Hydraulic Flow Characteristics of a Square-Edged Intake. Charles William Harris. 21 pp. 1932.
67. The Doherty Washer Cooler. Sybren Ruurd Tymstra. 61 pp. 1932.
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98. Geology and Its Relation to the Occurrence of Oil in Washington. Charles Edwin Weaver. 16 pp. 1938.
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100. Modernization of a Transit System. Factors that Determine the Choice of a Vehicle. George Lisle Hoard. 36 pp. 1940.
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102. An Investigation of Prestressed Stays. T. M. Rowlands and F. C. Smith. 36 pp. 1941.
103. Bismuth Bridge Magnetic Flux Meter. George Sherman Smith. 48 pp. 1940.
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110. Solutions for Torsional Vibration Frequencies by Energy Method. Arthur Melvin Winslow. 22 pp. 1943.
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5. Gaging Chart for Cylindrical Tanks with Different Types of Heads. Sybren Ruurd Tymstra. 7 pp. 1945.
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